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ELECTRICITY VERSUS STEAM FOR BRANCH RAILROAD LINES.

An Informal Discussion at the Annual Convention, June 30th, 1899.

SUBJECT FOR DISCUSSION.

"What are the economic conditions under which Electricity may be profitably substituted for Steam in the operation of Branch Railroad Lines, and what are the engineering requirements to be considered in such substitution?"

By Messrs. H. S. HAINES, H. G. PROUT, OBERLIN SMITH, W. B. REED, G. S. DAVISON, W. L. WEBB, J. JAMES R. CROES, W. J. BALDWIN, D. C. JACKSON, GUSTAV LINDENTHAL, EDWARD WEGMANN, ROBERT MOORE, C. W. BUCHHOLZ, A. P. DAVIS and CHARLES H. DAVIS.

Mr. Haines.

H. S. HAINES, M. Am. Soc. C. E.—As the speaker is responsible for the submission of this subject for discussion he will undertake to state the purpose he had in view in suggesting it.

Electricity has been gradually introduced as a motive power on railroads, first as a substitute for horse-car lines in cities; then into continually widening areas, with the extension of such lines into suburban districts; all the time offering more formidable competition to steam railroads, until it has become a question as to its substitution for steam on some of these very lines.

This problem has been attacked by one or two of our principal railroad systems in what may still be considered an experimental way,

Mr. Haines. and it would be a matter of public utility if the results so far obtained should be gathered together and be made more accessible by publication in the *Transactions* of this Society.

The profitable substitution of electricity for steam in a railroad motor probably varies with its application, whether to the traffic on a strictly suburban branch, or to a branch in a rural or manufacturing district. There is also to be considered the advisability of its application alternately with steam on the same line. The conclusion seems to have been reached that this substitution can be more profitably made where it is desired to move single cars frequently rather than where it is required to move heavy trains at infrequent intervals.

The speaker thought of this subject because of a case that occurred in his own experience. In planning quite a long main line, he had occasion to provide for several branch lines to reach factory sites or manufacturing villages, at varying distances from the main line, where a mixed train making one or two round trips per day might meet all the requirements, at least for a year or two after the branch lines were opened. In one case it would be practicable to obtain current from a factory where it was generated by water power. In this way his mind was directed to the subject, but he was not sufficiently familiar with the economic conditions affecting the transmission of an electric current and its use as a motive power to determine the question satisfactorily to himself, and hence its reference to the Society for discussion.

The speaker is aware that there is a phase of the discussion of this subject which is more appropriate to a conference of expert electricians, but it is not that phase which he has presented here. It is distinctly as an engineering problem that he asks for a solution. There is an apparent disinclination on the part of civil engineers to consider, as appertaining to their domain, the application of electricity in connection with engineering works, in the same way that they accept and discuss questions involving the use of water or steam power.

As a help to himself, and to others similarly interested, the speaker would like to have a discussion of the conditions under which it would be advisable to operate by electricity a branch line to a steam railroad, whether in a suburban, a manufacturing, or a rural district; the conditions including the length of the branch, the character and frequency of the traffic, the generation of the electric current by water power or by steam, etc.

The subject should be considered, not only with reference to lines with a large traffic, but also as applied to branch lines operated only by one locomotive with a single train crew, making one or two round trips daily.

If these conditions can be determined with approximate accuracy, the field for the application of electricity will be accordingly extended,

and perhaps it will thereby become more feasible to provide traffic facilities for communities, to which they cannot be profitably extended with steam as a motive power.* Mr. Haines.

HENRY G. PROUT, M. Am. Soc. C. E.—This question is pre-eminently one of traffic conditions rather than of strictly engineering conditions; although engineering covers traffic conditions. Under such requirements as Mr. Haines has suggested, *i. e.*, branch lines with infrequent trains, it would not be advisable to try to substitute electricity for steam locomotives; and it is quite likely that during the next few years light steam motors for such work will be developed. Mr. Prout.

The costly installation of the New York, New Haven and Hartford Railroad at Hartford and Berlin, Conn., will probably be found to be a very expensive and unremunerative experiment. It is said that about half of the machinery in the power house is lying idle and that one-car trains are run at intervals of twenty or twenty-five minutes. Under such conditions it is impossible to pay the interest on the cost of the installation. In other words, if the traffic is in units of considerable size at infrequent intervals the work can be done more cheaply by steam locomotives than by electricity.

A locomotive which will develop say 1 000 H.-P. will cost (we will assume) $10 000, and a power house and plant to develop 1 000 H.-P., will cost perhaps $80 000. Thus it will be seen that the interest on $70 000 has to be earned, or accounted for in some way by the superior economies of the electric installation.

It may be said that there will be a great saving in the fuel account, but careful analysis, made within the last three years, has shown that the fuel will cost as much per horse-power delivered at the rim of the driving wheel for electricity as for a steam locomotive. Although in a fixed plant cheaper fuel can be used, and with all the appliances of automatic stoking, etc., can be burned more cheaply than in the steam locomotive, yet the losses in efficiency of the generator, in transmission, and in the motor, are sufficient to overcome that saving, and by the time the power is delivered at the rail it will have cost as much in coal as by the locomotive. This seems to be a safe general proposition, although Mr. Baker, General Superintendent of the Manhattan Elevated Railroad, has lately said that many improvements have been made within the last year or two, and greater efficiency is obtained from the generators and motors. But even if a saving in coal of, say, 50% can be made, yet, after all, the fuel item in the operation of a railroad is comparatively small. Assuming the fuel element to be about 13% of the total operating expenses, then, even if the saving in this item is 50%, it is evident that little has been saved toward paying the interest on the expensive electric installation.

If the traffic is such that its efficiency, or commercial development,

* For further remarks by Mr. Haines, see p. 386.

Mr. Prout. requires a minute subdivision of the units, that is, a division into very small units running very frequently, in order to induce traffic to move, then, of course, electricity will win, not because it is cheaper than steam, but because it is adapted to such minute subdivision.

Mr. Smith. OBERLIN SMITH, M. Am. Soc. C. E.—For several years past the speaker has publicly advocated the use of small electric motors for driving machine tools and other independent machines. Although the idea at first appeared somewhat chimerical, individual motors are now extensively so used, the system having mostly passed beyond the experimental and transitional stages.

Railroad motive power is now in a state of transition. Within the last ten years the ordinary street trolley line has grown from a mere experiment into a great industry, which has not only performed the work of the horse-cars it displaced, but has created an enormous traveling habit. The time for the universal use of these motors on railroads has not yet arrived, but the speaker believes that it will come eventually, in consequence of discoveries which will cheapen the use of fuel and simplify electrical machinery; and also because such a method will result in greater convenience to travelers, by reason of more smoothness of motion, freedom from dust, smoke, cinders, etc., and facility for running single cars (or short trains) at much more frequent intervals than now. It therefore follows that the use of electricity on roads which are at present run by steam, will largely increase travel—and the habit of traveling. Such improvements make car riding a pleasure rather than the duty that it now often is.

The foregoing remarks apply to travel on surface roads, at speeds much the same as now practiced. The change in method has already begun, and its adoption by all railroads is simply a matter of relative cost—in construction, maintenance and operation.

It would seem probable, however, that in the next generation, if not in this, an entirely new type of high-speed railroad will be developed. Mechanically, the world is ready to begin it—financially, not yet, for its cost would be great. Upon some special type of track, confining the cars absolutely against derailment, a speed of 120 to 150 miles per hour, and possibly more, can doubtless be obtained; and it would not seem to be a very wonderful feat to cover the 90 miles between New York and Philadelphia in half or three-quarters of an hour. There are no physical or mechanical obstacles which cannot be overcome with our present knowledge and some experimenting with details.

The danger of collision with other objects can be avoided by the use of an elevated roadway with absolutely no crossings, turn-tables or switches; and with the trains run upon a positive electric block system, in one direction on one track.

The questions of derailment and collision being obliterated, the

speed of trains will be limited only by air resistance and by the strength of the wheels to resist centrifugal force—if wheels are used. If the cars are made long, narrow, pointed, very smooth and properly jointed together when in trains of more than one, they can probably be run at high speed without encountering such great air resistance as would make the cost of power too great. Such cost, however, must not be based upon present train weights in relation to live load. Mr. Smith.

In an article in the *Forum*, for January, 1891, the speaker showed that the dead weight carried on American railroads, in many cases, amounted to 6 tons per passenger on trains of Pullman cars, and that a load of 1 or 2 tons per passenger is very common. From a mechanical standpoint this excessive weight is not necessary. The bicycle has shown that a person can be carried over a smooth dirt road with 20 lbs. of dead load, and on an iron pathway this can be further reduced; if riding on a tricycle covered from the weather, as in a car, this load might be 150 lbs., or about his own weight.

In this respect the bicycle has been an object lesson, and has shown that it is possible for a vehicle to be so delicately made, to have so much refinement in its mechanical design and composition, with ball-bearings, steel suspension-spokes, tubular frames, etc., that our old notions of wagons and cars appear absurd in comparison, especially when we carry 6 tons, or even 1 ton, of dead weight for each passenger.

It has been demonstrated that a heavy steam locomotive and train can travel upwards of 100 miles an hour, with all the disadvantages of a tremendous load not on the drivers, and a degree of uncertainty as to whether or not the train will stay on the rails. If, however, such a train could be made safe upon a surface road, at the speeds under consideration, and did it not cost too much for power, yet there are limitations of speed in respect to getting steam through the ports quickly enough and in working reciprocating members—as pistons, connecting-rods, etc. These limitations do not exist with rotating electric motors.

It would seem likely, therefore, that some of us may live to see some such railroading as has been indicated—a service safe, rapid and frequent, developed at first over short distances between very large cities. Should we succeed in adapting to the axles some form of suitable roller-bearings, we will save as much power as possible under the circumstances. Should we, further, be fortunate enough to find it practicable to equip our wheels with rubber tires, or some yet to be discovered equivalent, we then might get a smoothness and quietness of running which would indeed proclaim the advent of the ideal railroad.

One reason why electricity works better upon steep grades is that, with the best modern systems, every wheel in the train can be made a driving wheel. A train can be comparatively light, without the dead

Mr. Smith. weight of a locomotive, and yet have sufficient traction. With a steam train we not only have the cars very heavy, especially Pullman cars, but we have the big locomotive itself to drag up grades, with only the adhesion due to the weight of part of the locomotive, such as happens to be on the drivers. This is evidently very different from being able to have a very light train and making every wheel a driver, with every pound of the train and load contributing its share of adhesion.

Mr. Reed. W. B. REED, Assoc. M. Am. Soc. C. E.—The discussion, up to this point, has referred mainly to passengers. The question of carrying freight in combination with passengers, upon electric lines, should also be discussed. Generally speaking, it has been found that for short distances passengers can be carried more comfortably and more cheaply by electricity than by steam, but in the carrying of freight little has been done by electricity as yet. That is a feature which will grow in the future.

When freight is to be carried over passenger lines by electricity it will have to be taken through city streets, or at least over highways, and the rails should be designed to meet the conditions of electric cars which have shallow flanges; freight cars with deeper flanges, and which vary more or less in gauge, requiring not only a deep groove but a wide flangeway; and the ordinary vehicle traffic.

Mr. Davison. G. S. DAVISON, M. Am. Soc. C. E.—About 8 or 9 years ago the speaker was in charge of the construction of a small branch line near Pittsburg which was required to connect a small manufacturing town with the Pittsburg and Lake Erie Railroad and the Pennsylvania lines. It was an independent corporation, controlled by manufacturers in the town, and it was equipped at first with steam power. The president of the company conceived the idea that with such cheap fuel as is to be had in that neighborhood, and in view of a proposed change in the future from steam to water power, it would be proper to operate this branch by electricity instead of steam. He experimented slowly, and equipped the line as a trolley road, but separated the passenger and freight traffic, and carried the former by electricity and the latter by steam locomotives.

The speaker does not know the results of the operations of this company, but judging from later occurrences he believes that the separation of the passenger and freight service was found to be a mistake. In this case the company had ideal conditions for cheap fuel, and had also its own electric power plant. It was not necessary to install a new plant, but simply to add to the old.

The road was afterward purchased by the Pittsburg and Lake Erie Railroad Company, and is now being operated as a branch of that road. The company, on acquiring this branch line studied its operation to determine whether it should be conducted as an electric line in part or as a whole, or whether it should be operated as a

steam road. As the electrical equipment was discarded and as the road is now being operated by steam, it may be assumed that electricity was found to be uneconomical. The causes which led to this change are not known to the speaker, but he suggests that possibly the trolley equipment might have been found very inconvenient when operating the road by steam as a freight line. The third-rail system may prove to be more practicable than the trolley in such cases, but the latter must be excluded on account of its inconvenience. Mr. Davison.

In the vicinity of Pittsburg there is a large mine which is operated for some 7 miles back from the point where the coal is brought to the tipple; the means of bringing the coal to the opening being virtually a small branch railroad. This branch passes through several tunnels and has been operated as a steam railroad for a number of years. At the present time the first 5 miles of the road is being operated as an electric line, using the trolley system, and on the remainder of the line, next to where the coal is brought out to the tipple, steam locomotives are used. The owner stated that the operation had been planned in that way, and that they had been justified in hauling the coal the first distance by electricity, because the use of steam locomotives in the mines was detrimental to the health of the men. But, taking full account of the cost of installation, power, etc., they had not found that it would be cheaper or better to continue the use of the trolley to the tipple.

The fuel of this power station is delivered directly from the mine into the boiler house, and yet, on the 5 miles operated by electricity, the saving on fuel is so small that the expense of an electric equipment for the remaining 2 miles would not be justified.

As the topic for discussion refers only to the operation of branch roads, in connection with a main line, Mr. Smith's proposition to attach a motor to every axle on the train would seem to be impracticable as it would involve the equipment of every car of the trunk line so that it could be used on the branch.

WALTER L. WEBB, Assoc. M. Am. Soc. C. E.—The relation of grades to the question of steam or electric operation has not yet been touched upon in this discussion. On a steam railroad, a grade of 2% is considered steep, while 4% marks almost the limit of working on such roads; yet on many of the electric railroads in the United States there are grades of 10% and even steeper. On steam roads which are steep in some places and flat in others there is a great waste of power. This occurs, not on the heavy grades where the engines are hard worked, but on the light grades where the great reserve power—at those points doing practically no work—has to be maintained for service on the heavy grades. On an electric road the amount of power used is almost proportional to the work to be done, and this is an important element in its economy. On a railroad in a mountainous region it Mr. Webb.

Mr. Webb. should be possible to adopt a cheaper form of construction than is necessary for a steam road with its requirements of low uniform grade, and to use freely very steep grades where desirable. Assuming a fair amount of traffic, so distributed as to keep the road in uniform operation, electricity will, in many cases, prove more desirable than steam locomotives, taking into consideration the interest on the cost of the construction and installation, and the expense of operation, and this will be true for these reasons alone, to say nothing of the possible economies consequent on a utilization of water-power.

Mr. Croes. J. JAMES R. CROES, M. Am. Soc. C. E.—The economical generation of power, either steam or electric, implies a constant and continuous operation of the generating plant. When variable power is needed, the generating plant must be constantly operated at its maximum efficiency. When the work to be accomplished can be distributed over a continuous period of 10 to 24 hours, the power can be more economically generated by an indirect application through a stationary plant than by a direct application of the fuel to the motor, as in the steam locomotive. Where, however, the work involves a spasmodic application, occupying only a limited amount of time, at irregular periods during the day, the generation of power by an independent motor, capable of producing in itself the power needed, is more convenient and more economical than its production by a central plant.

Steam power at the present day can be generated spasmodically more efficiently than electric power. The requirements of railroad service on a line of limited traffic are spasmodic, reaching a maximum at certain hours; and until a storage battery has been devised in which the power produced continuously can be stored and used for spasmodic application, which application shall satisfy a maximum call greater than the average efficiency required of the generating plant, electricity cannot be applied more economically than steam. At present, it seems to the speaker that where the work is spasmodic, steam power is, and must be, more economical than electric power, for branch railroads.

Mr. Baldwin. WILLIAM J. BALDWIN, M. Am. Soc. C. E.—In many States the warming of cars is obligatory by law, and the cost of heating should therefore be taken into consideration in a comparison of railroad operation by steam and by electricity. About three years ago the speaker had occasion to test an electric heater. There was no unit of measurement to be determined, but the heater furnished was found, by comparison, to agree with 28 ft. of steam-heating surface. It was found that 28 ft. of steam-heating surface will condense about 7 lbs. of water in an hour, or about 0.25 H.-P. The electric heater, practically the equivalent of the heating surface mentioned, required between 6 and 7 electric H.-P. The result of this test indicates that warming by electric heaters requires 27 or 28 times the horse-power needed to warm by steam.

D. C. JACKSON, M. Am. Soc. C. E.—There is no mystery about this matter, and Mr. Croes has well stated the case. It is more economical —not more efficient—to generate power for operating a railroad or a group of manufacturing establishments at a central station only when the power can be used continuously over long hours, for the reason that when the traffic on the railroad or the load on the motors at the manufacturing establishments is continuous, the demand on the central station for power is continuous, and the cost for interest and labor per horse-power hour developed by the station is brought to a reasonable figure. Where traffic requirements are intermittent, it is more economical to operate a railroad by steam locomotives. If a plant of 1 000 H.-P., installed to operate a branch railroad with freight traffic, is called on for its output for only 3 hours of the day, 24 hours of interest charges lie against the 3 hours of output. There are at the station, daily, possibly 10 hours of full labor and 14 hours of one-half or one-third labor, and if this is charged against the 3-hour output, it makes the cost of operating the station, per horse-power hour, enormous. Whether or not, electric power may be economical in various cases is, as Mr. Prout has said, a matter of the distribution of traffic. Mr. Jackson.

These remarks apply equally to electric power plants where the prime power is derived from steam engines or water wheels. The larger cost of development of a water-power plant will often cause an excess interest charge which is equal to the cost of fuel in a steam plant designed to do the same work, and the average small water-power plant does not embrace such economical advantages as are generally ascribed to it.

The case of a main-line feeder, as put by Mr. Haines, is a special case under the general proposition, and under some circumstances it is possible that electric power can handle the traffic most economically. These conditions would assume a number of main-line feeders, located reasonably near a given point, so that the entire load of all these branches may be carried by a central station, using a fairly high transmitting pressure. The traffic should be broken into units somewhat smaller than would be operated ordinarily by steam power direct, and schedules of train movements should be so arranged that the station may be fairly well loaded during at least 12 hours. If the schedules are so arranged that once or twice during the day a single mixed train will be running simultaneously over each of these branches, the speaker doubts if electric power, from the point of view of dollars and cents, can ever compete with the steam locomotive.

Referring to the requirements for the electric heating of cars, some of the western electric street railways make provision for turning into the heaters during cold weather, as much power as is required to move the cars. In other words, in very cold weather, a station output of double that necessary to handle the cars is anticipated.

Mr. Lindenthal. GUSTAV LINDENTHAL, M. Am. Soc. C. E.—In discussing this question an important feature is the ability to store electric power. In recent years several electric power plants have been so constructed that, when running at a uniform rate, the power generated in excess of current demand could be stored up in secondary batteries acting as reservoirs, to be given out again whenever the demand for power exceeds the capacity of the plant.

A railroad train in descending a grade wastes power in grinding up brake shoes, and heretofore this power has not been stored in any form. It is possible to generate and store that power in the form of electricity, which can be used again in hauling trains or cars up an ascending grade, or for lighting or heating purposes. The speaker believes that the feature of storing electric power should have an important bearing in any comparison of the economies of locomotive and electric traction, particularly in mountainous countries where coal may be dear and water-power cheap.

Mr. Wegmann. EDWARD WEGMANN, M. Am. Soc. C. E.—The speaker objects to the statement that steeper grades can be used on electric tramways than on ordinary steam railroads. While it is undoubtedly true that steeper grades are used on trolley lines than on ordinary railroads, this difference should not be credited to electricity as against steam, but to the placing of a motor under each car. If a steam engine were applied to a car in this manner, the car could be driven up any of the grades to be found on trolley lines.

Before any trolley lines had been constructed the speaker had spent two or three years in assisting an inventor in developing and introducing a steam street car, which was run successfully in Brooklyn. This car, which was propelled by a small three-cylinder steam engine, placed between the axles and suspended from the car frame, was able to run up 10% grades.

While such a car might be used to advantage, where only a few trips had to be made each day, it had several disadvantages compared with trolley cars: 1st, The weight of the boiler was objectionable; 2d, A licensed engineer was required for each car. One of the great advantages of the trolley system is that men of ordinary intelligence can soon be taught to run the cars.

In the case of pulling a train by a special motor, the grade that could be overcome depended, as was well known, on the weight on the driving wheels, the rolling friction of the wheels, and the weight of the train. It made, therefore, no difference as regards the grades, whether steam, electricity, compressed air, or any other motive power were used to propel the motor.

Mr. Moore. ROBERT MOORE, M. Am. Soc. C. E.—Each particular case of this kind must be considered by itself. In the case indicated by Mr. Haines, in which the power is to be rented and paid for, presumably,

by a meter, the conditions of economy would be very different from those in which the railroad company would be required to install the plant, and bear the cost of the current whether it were being used or not. Therefore a proposition which would cover all cases might be very delusive. So far as a general proposition can now be made it must be substantially as indicated by Mr. Prout. Mr. Moore.

When the conditions are those of an urban traffic—a very large number of small trains—electricity has abundantly demonstrated its superiority over every other form of motive power; but when the conditions are very different from those of urban traffic—when the trains are infrequent or heavy—the speaker doubts its economy, and sees no indications that it is likely to be economical in the near future.

Regarding the superior economy claimed for the electric motor on heavy grades, the point cited by Mr. Wegmann is a sufficient answer. The power is developed only by the traction of the driver on the rail, and that is a function of its weight; thus, there can be no saving in that respect. But there is another point which should not be lightly regarded, the great danger, in operating on very steep grades, of the failure of brake power. Any such failure means disaster, as many who have had occasion to operate heavy grades well know.

In fact, if, with a possibility of doing otherwise, any one is tempted to use heavy grades, the best advice to follow is that of *Punch* to those about to be married—"Don't."

C. W. Buchholz, M. Am. Soc. C. E.—The facts are against the assertion that the grades on an electric road can be steeper than on a steam road. The power of a locomotive depends upon its adhesion to the rail, and it makes no difference whether the power is steam or electricity. Mr. Buchholz.

A. P. Davis, Assoc. M. Am. Soc. C. E.—This question is, without doubt, one of the kind of traffic, and to one more familiar with hydraulics than with railroad work, it appears to be a matter of saving, not 20, 40 or 50% of the fuel, but all of it. It has been pointed out that electric power makes its best showing in the mining regions, and one of its chief advantages seems to be that on steep grades it requires less dead weight than steam power, an important point in regions where steep grades are unavoidable. In mountainous regions the railroads, both main and branch lines, follow the streams, sometimes of heavy fall, where water power can be developed cheaply. In many cases in the West a water-power plant would not be chargeable with the total expense of the development, for whatever of diversion works and storage facilities are required are equally available as parts of an irrigation system which will receive the water after it has been used for power. Mr. Davis.

Two lines of railroad extend up the line of the Arkansas River,

Mr. Davis

cross the Rocky Mountains and follow the Grand River down on the other side. There, where coal is much more expensive than in the East, is an immense amount of power, constantly going to waste, which might be utilized by the electric system to move those frequent and heavy trains. Undoubtedly, the time is approaching when a great saving can be made in equipping with electric power, not only branch lines, but main roads as well, through mountainous regions, where water power is available. Improvements in the transmission of power are still possible, and the utilization of water-power in railroad operation is mainly a question of transmission. As transmission methods are improved, and as railroad traffic in such regions increases, the advantage of electric over steam power will be demonstrated with a definiteness to which the probable advance in the price of fuel will add its contribution.

Mr. Haines.

H. S. HAINES, M. Am. Soc. C. E.—This question was suggested by the speaker because he considered it to be of practical moment, and because he desired to obtain from members of the Society an authentic expression of opinion as to how far, in the present state of the art, it was advisable to substitute electricity for steam as a motive power on branch lines of steam railroads.

If electricity is used on branch lines it must be used in connection with the vehicles in which passengers and freight are transported on the main lines. It is not only desirable to ascertain what can be done with electricity under this aspect of the case, but also what cannot be done. There is one general proposition that all will accept, viz., that in the present state of the art there is no doubt that electricity can be economically substituted for steam on a branch of a steam railroad where there are single units of transportation moving at frequent intervals, because the power can be used uniformly and continuously and because a large plant is not lying idle for the greater part of the time.

To state the cases in which electric transmission cannot be applied, a process of exclusion must be used; therefore, let it be said that it can be applied economically on branch lines for suburban purposes. If that is the case, it strengthens the steam railroads which have suburban branches competing with trolley lines. This seems to have been the idea which has prevailed in the minds of the management of some of the principal railroad systems operating out of large centers of population. The speaker recently had occasion to talk this matter over with some of the principal officials of the New York, New Haven and Hartford Railroad, who have probably had more experience in this matter than anyone else; and the impression received was that they are quite well satisfied with what they have done thus far in an experimental way, and they are extending the system. There is one point, however, which they have not yet determined, and that is, the con-

ditions under which the third rail should take the place of the trolley wire. Mr. Haines.

Admitting that electricity can be used economically on suburban lines the next question is: Can it be used on branch lines under other conditions? Judging from the preceding discussion the speaker believes that electric motors might be used to great advantage on branch lines in a manufacturing district, even for handling freight, if power can be obtained along those lines from manufacturers who have it to spare.

On a line running into a rural district it would seem hardly practicable to use electricity, unless, as Mr. A. P. Davis remarked, water-power could be obtained. That was one of the conditions in the case which was being considered by the speaker. The main line was for some miles parallel with a stream which it was intended to develop for manufacturing purposes; but the line ran along a ridge and the water-power was down in the valley. If branch lines could be run down into the valley the water-power there could probably be used more economically than steam.

The speaker need not discuss the question of heavy grades, as that has been covered so well by Mr. Buchholz. Unless by the use of electricity the traction can be made stronger than the mere adhesion due to the weight of the locomotive, that question need not be considered.

To sum up, it may be said that in the present state of the art it is only admissible to apply electricity on what may be called suburban passenger lines; except that it may be applied where power, for certain local reasons, may be obtained more cheaply than by means of the steam locomotive.

Mr. Davis.

Charles Henry Davis, M. Am. Soc. C. E. (by letter).—While the subject for discussion seems to be confined to the application of electric motive power to branch steam railroad lines, the members speaking on this subject, at the Annual Convention, June 30th, 1899, are evidently interested in the problem as a whole and have not confined themselves to "branch lines." Claiming the same privilege, the writer transmits the following as possibly throwing some light on the future development in the use of electric traction, not only on existing steam railroad lines, but for new high-speed interurban transportation systems.

Reversing the usual order, some of the writer's conclusions are given prior to the discussion, in order that each step may be followed more readily. The figures and tables may be found to have some errors (of which the author will be glad to be advised), and, in many cases, are only approximate; so that they must not necessarily be treated as accurate in their details, but they are safe as to their conclusions, and can be relied upon in this respect.

Mr. Davis.

CONCLUSIONS.

(*1*) Steam railroads will, in the near future, handle their suburban and short-distance interurban passenger traffic and mail, express, baggage and light local freight carried in said suburban and interurban passenger trains, by electric motive power; and this, irrespective of whether operating expenses are affected favorably or unfavorably.

(*2*) Steam railroads will not, in the near future, handle their freight traffic (other than mail, express, baggage and light local freight carried in suburban and interurban passenger trains), and long-distance passenger traffic by any other motive power than steam locomotives.

(*3*) Steam railroads may, under exceptional conditions of large volume and great density of passenger traffic over distances longer than under (*1*) and shorter than under (*2*), handle it by electric motive power, but such cases will be infrequent.

(*4*) New railway lines, connecting very large centers of population, where frequent service at much higher speeds than can be attained now by steam locomotives on existing lines are conditions of success, will be operated by electric motors.

There are three conditions under which suburban and short-distance interurban traffic will be handled profitably by steam railroads converting to electric traction:

1. (*a*) Where units can be light and frequent, and operated over comparatively short distances.

(*b*) Where gross receipts can be so increased by the change of system and mode of operation as to pay for the increased investment and possible increase in operating expenses.

(*c*) Where competition of parallel electric roads compels the change, to save what traffic there is, irrespective of how operating expenses are affected.

In the future development of steam railroad systems they will eventually be operated jointly with surface electric railways, either through actual mutual ownership or by traffic contracts, leases, etc.

The above conclusions are obviously dependent upon what Mr. Prout properly defines as "traffic conditions," and not primarily engineering details or operating expenses.

Laws of Passenger Traffic.

The laws of passenger movement are not well defined, and many of them are illusive and hard to determine; the causes of loss or gain are often largely a matter of individual judgment, so that the following outline of them must not be taken as in any way exact.

People travel from one place to another from (1), necessity, and (2), pleasure or whim.

They are induced to travel more or less often according to:

1. Total Cost from Point of Departure to Objective Point and Return to

Mr. Davis.

EXPLANATION

Curve		Multiplier for Vertical Scale
1.	Total Miles of Track	1 000
2.	Annual Increase of Mileage	100
3.	Total Population of the United States	1 000 000
4.	Percentage of Increase of Population of United States	1
5.	Density of Population of the United States	1
6.	" " " " Massachusetts	2
7.	Total Urban Population of the United States	100 000
8.	Percentage of Urban to Total Population of the United States	½
9.	Total Population of New York, New Jersey and Pennsylvania	100 000
10.	" " " Massachusetts	100 000
11.	" " " New York City	10 000
12.	" " " Brooklyn	10 000
13.	" " " Philadelphia	10 000
14.	" " Served by N.Y.& P.R.T.R.R.	100 000

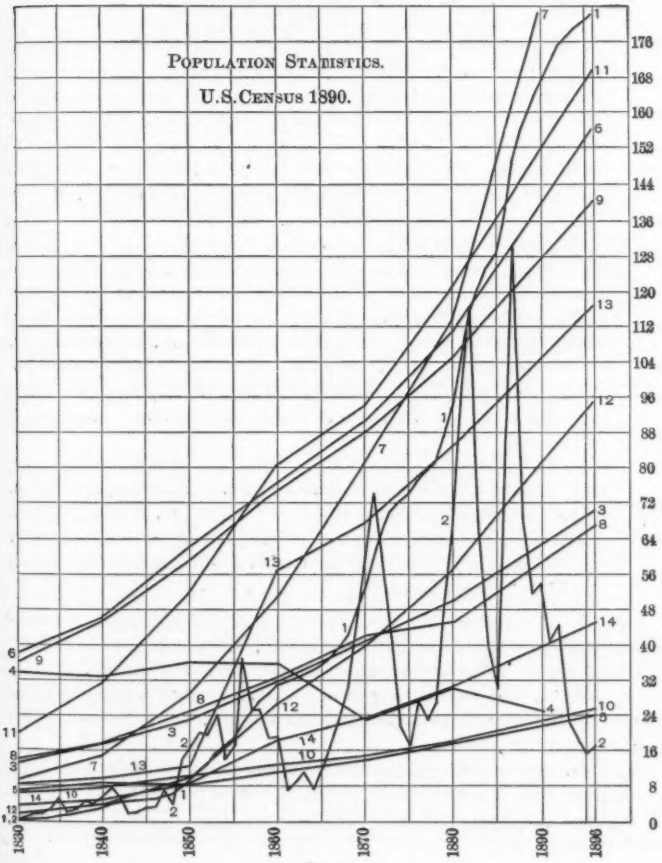

FIG. 1.

Mr. Davis.

Place of Beginning.—As the total cost is reduced, travel, due to both fundamental causes, is increased; presumably less rapidly than the total cost falls. Note that the important factor to the passenger is total cost, and not cost per mile traveled.

2. *Total Time Consumed in Making the Round Trip.*—As the total time consumed is reduced, travel, due to both fundamental causes, is increased, presumably less rapidly than the total time falls. Velocity of transportation is not primarily effective in inducing travel, for it makes no difference to the passenger whether he be carried 80 miles in 30 minutes or only 12 miles.

3. *Total Conveniences Afforded the Passenger.*—These may be divided into:

(*a*) Proximity of departure and arrival points to possible passengers. As a "leave-at-your-door" service is approached, passenger traffic increases, but according to no known ratio to distance. Wellington laid down an approximate rule of loss of natural revenue for steam railroads of 10% per mile of removal from center of population as a minimum, 25% per mile as an ordinary maximum and a much larger percentage of loss, or even total loss, under certain conditions. Electric street railways have profited more by this kind of service, which they offer the public, than from any other reason; in furnishing it they give frequent and quick service, both of which are of the greatest importance in their effect on passenger traffic. Much less than a mile, however, will make or ruin the passenger traffic of a street railway.

(*b*) Frequency of the service. As the number of trips increases, so will the passengers, but less rapidly than the headway is shortened. A frequent service means less "total time" consumed.

(*c*) Character of terminals, stations, roadbed, equipment, and, in fact, all physical characteristics. That transportation system which offers, at the same rate and time, better physical conditions, which give comfort or even luxury to the passenger, will not only secure competitive traffic, but induce that which would not otherwise exist.

4. *Total Population.*—As the population served increases, the passenger trips per capita per annum increase, and somewhat faster than the inhabitants, unless modified by density and distribution.

5. *Density.*—As the density increases, it is probable that the rides per capita per annum also increase, but whether more or less rapidly is uncertain.*

6. *Distribution.*—A long, narrow town will give more rides per capita per annum than a square town having the same population.

* In an earlier publication the writer expressed the opinion that the increase was less rapid than the density, but wishes to leave this open for further investigation.

Mr. Davis.

EXPLANATION.

Curve.		Multiplier for Vertical Scale.
1.	Total Miles of Track	10
2.	Annual Increase of Mileage	10
3.	Total Capital Stock, in Dollars	500 000
4.	" Bonded Debt " "	500 000
5.	" Capitalization " "	500 000
6.	" " per Mile of Track, in Dollars	500

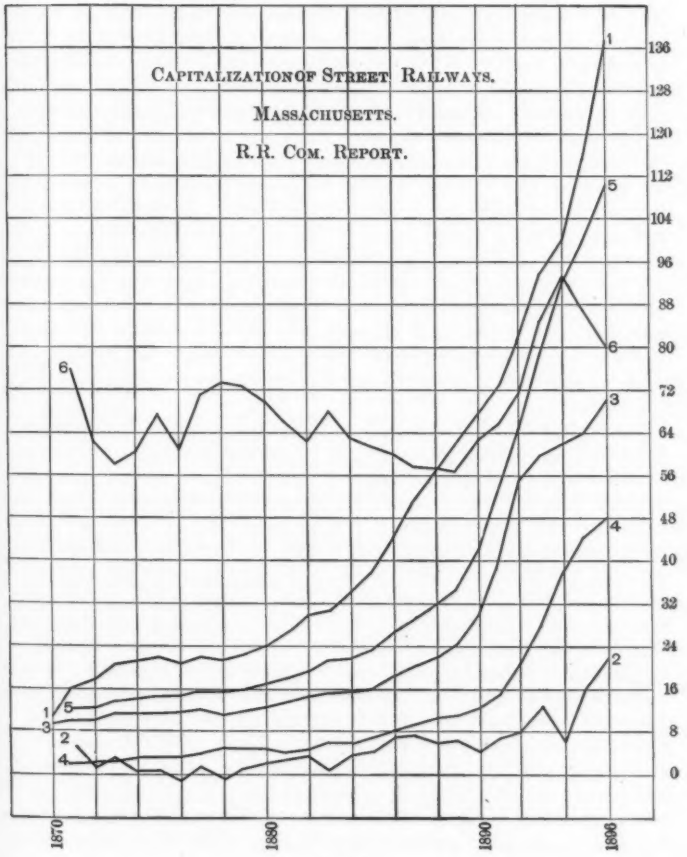

FIG. 2.

Mr. Davis. 7. *Character of the Industries and Population.*—The effect of various industries and the kind of population must have a decided effect on the passenger traffic, but probably according to no fixed laws, and certainly according to no known laws.

No "detailed defence" is offered for these laws other than what support they may obtain from the following discussion.

Any management of a steam railroad, in considering the question of adopting electric traction, will naturally turn first to data on operating expenses, for, if its use should lower the cost per train or car-mile enough to more than pay interest on the investment, then it would be of advantage, even though there were no other inducements, such as increased traffic. While comparisons might be made between the operating expenses of steam railroads, which are now well known, and such electrically operated roads as the Chicago Elevated Railways, or the third-rail lines of the New York, New Haven and Hartford Railroad, yet there are disadvantages in doing so which outweigh the apparent one of more similar conditions than exist between the ordinary street railway and the steam railroad. If it should appear that the operating expenses of electric street railways per car-mile are less than the cost per car-mile operated on steam railroads, one can be certain that electrical operation, applied to the latter, will result in reduced expenses. Whether or not this reduction will be enough to pay for the change is another question. For these reasons, a comparison between the street railways and steam railroads of the New England States has been taken as a basis in this discussion.

To exhibit the relative merits of the two systems of installations, the following divisions are arranged in tabular form and are treated in order. The prefixion of the word "electric" or "steam" indicates that the item belongs exclusively to one or the other system and has no counterpart in the other.

In comparing the steam and electric roads of New England, we are more likely to arrive at correct conclusions, as the population is more dense, the miles of road greater per square mile, there are many more examples to study, and the statistics are more accurate and reliable, and cover longer periods. The word "Railroad" is used to designate a "steam railroad," while "Railway" always indicates an "electric street railway," following Massachusetts precedent; the difference being that the former operates on its own right-of-way, while the latter occupies the public highway. This distinction is a desirable one to cultivate, and should be extended and used irrespective of the mode of operation; thus, a road operating by steam, electricity or any other motive power on its own right-of-way is a "railroad," and one operating on a public highway is a "railway."

EXPLANATION.

Curve.		Multiplier for Vertical Scale.
1.	Total Miles of Track	100
2.	Annual Increase of Mileage	10
3.	Total Capital Stock, in Dollars	10 000 000
4.	" Bonded Debt " "	1 000 000
5.	" Capitalization " "	10 000 000
6.	" " per Mile of Track, in Dollars	1 000

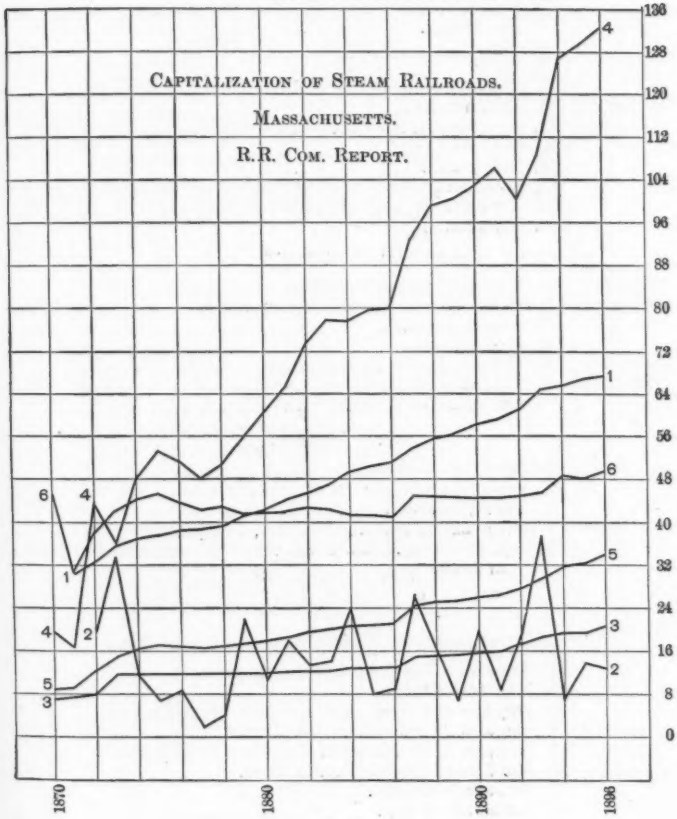

FIG. 3.

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TABLE No. 1.

1. FIRST COST.

(*a*) RIGHT-OF-WAY AND REAL ESTATE.

(*b*) CONSTRUCTION.

1. Engineering and surveying.
2. Clearing.
3. Grading, ditching, etc.
4. Tunnels.
5. Masonry, culverts, bridges, trestles.
6. Fencing, cattle-guards, road-crossings.
7. Ballasting.
8. Ties.
9. Rails.
10. Track-laying, lining and surfacing.

(Electric) 11. Rail bonding.

(Electric) 12. Overhead-trolley line, or third rail.

13. Signals.
14. Telegraph.
15. Stations and all buildings (including buildings for central power stations of electric roads).
16. Terminals.

(*c*) EQUIPMENT.

(Steam.) 1. Locomotives and tenders.

(Electric) 2. Motor cars or electric locomotives.

3. Passenger cars.
4. Freight cars.

(Electric) 5. Electric feeder lines and ground-return circuit.

(Electric) 6. Central power stations (not including buildings which are considered under "Construction").

(*d*) GENERAL.

1. Discount on bonds.
2. Interest on bonds, to opening of road.
3. Taxes, to opening of road.
4. Office expenses, salaries, etc., to opening of road.
5. Contingent and miscellaneous, not itemized, to opening of road.

2. TOTAL EXPENSES.

(*a*) MAINTENANCE AND RENEWAL OF WAY AND WORKS.

1. Repairs of earthwork to subgrade.
2. Repairs of track.
3. Repairs of fences, cattleguards, crossings, etc.

(Electric) 4. Repairs of ground-return circuit.

(Electric) 5. Repairs of overhead-trolley line, or third rail.

(Electric) 6. Repairs of electric feeder lines.

7. Renewals of rails.
8. Renewals of ties.
9. Renewals of ballast.

(Electric) 10. Renewals of poles, or insulation of third rail.

(Electric) 11. Renewals of trolley, or third rail.
(Electric) 12. Renewals of feeders.
13. Repairs of masonry, bridges, trestles.
14. Repairs of buildings.
15. Repairs of signals.

(*b*) TRAIN EXPENSES.

(Steam) 1. Fuel for locomotives.
(Electric) 2. Fuel for power stations.
3. Water supply.
4. Oil and waste.
(Steam) 5. Repairs and maintenance of locomotives and tenders.
(Electric) 6. Repairs and maintenance of motor cars or electric locomotives.
7. Repairs and maintenance of passenger cars.
8. Repairs and maintenance of freight cars.
9. Use of foreign passenger and freight cars.
(Steam) 10. Locomotive services (wages).
(Electric) 11. Motor car or electric locomotive services (wages).
12. Passenger-train services (wages).
13. Freight-train services (wages).
(Electric) 14. Repairs and maintenance of power stations.
(Electric) 15. Power-station services (wages).

(*c*) STATION, TERMINAL, TAXES AND GENERAL EXPENSES.

1. Agents and station services (wages).
2. Station supplies.
3. Telegraph.
4. Taxes.
5. General officers and clerks.
6. Legal.
7. Insurance.
8. Stationery and printing.
9. Agencies and advertising.
10. Contingent and miscellaneous, not included above.

(*d*) ACCIDENTS, LOSS AND DAMAGES.

1. To freight.
2. To passengers.
3. To property owned.
4. To property not owned.

(*e*) INTEREST ACCOUNT.

(*f*) FIXED CHARGES.

1. Interest on bonds.
2. Rentals.

(*g*) DIVIDENDS.

3. GROSS RECEIPTS.

1. Passenger receipts.
2. Freight receipts.
3. Miscellaneous receipts.

1. First Cost.

Mr. Davis. We shall consider a new line under steam-railroad conditions, first, and then a change of system on an existing railroad.

The first cost of (*a*) "Right-of-Way and Real Estate" cannot be affected by any particular motive power unless the use of electric traction permits the use of sharper curves and heavier grades, thus avoiding large cuts or fills. While a coupled locomotive undoubtedly increases "curve resistance," this is not sufficient to be of any great moment. If electric motors are applied to every car axle, then trains of the same weight, moved by electricity, can surmount heavier grades than with locomotives or can pass over the same grades at higher speeds. Hill climbing is a matter of traction between driven wheels and rails, and the sustained horse-power of the motor or locomotive. With the power applied to every axle, there is no part of the load which remains unutilized for traction, but this cannot be done by the application of steam, and has, as yet, been only partially successful with electric motors. With the latter, their maximum power can be called upon for an indefinite time, because they do not give out at the top of a long, heavy grade. This advantage of electric traction is, however, only apparent; first, because long trains are not yet satisfactorily controlled where motors are put on every axle, and short trains of two to five cars have only half the axles supplied with power in present practice; and second, electricity being confined to suburban and interurban short hauls between large centers of population, the additional cost of avoiding heavy grades is comparatively small, and furthermore, if they are not avoided the loss in time would result in a correspondingly larger loss of revenue.

Under (*b*) "Construction" we find that items 11 and 12 apply to electric traction only, while there are no items applying to steam-locomotive traction only. These items might have been placed under the heading "equipment," as part of the things necessary in electric traction to replace steam locomotives and which could be added to motor cars or electric locomotives as equipment for an electric road. This phase of the question will be discussed under the heading "equipment." The engineering of an electric line might cost more than that of a steam road, but not necessarily; if the chief engineer was a competent railroad man with a thorough knowledge of electrical engineering, the cost would be the same; otherwise it would be increased by that amount paid an assistant engineer with special electrical knowledge, unless the line was costly enough to warrant several assistant engineers, one of whom could be versed in electrical matters.

The cost of surveying work, consisting of reconnaissance, exploration line ("shoo-fly"), preliminary, location, and their modifications or extensions, depending upon the importance of the line, its cost,

EXPLANATION

Curve.		Multiplier for Vertical Scale.
1.	Gross Traffic Earnings, in Dollars.	100 000
2.	Total Interest on Bonded Debt, in Dollars	10 000
3.	" Dividends on Capital Stock, in Dollars	10 000
4.	Gross Traffic Earnings per Mile of Track, in Dollars	100
5.	Percentage of Expenses to Gross Earnings	1
6.	" " " Interest paid on Bonded Debt	1/10
7.	" " " Dividends " " Capital Stock	1/10
8.	Gross Earnings per Revenue Train-Mile (Car-Mile), in cents	1
9.	" Expenses " " " " " " " "	1

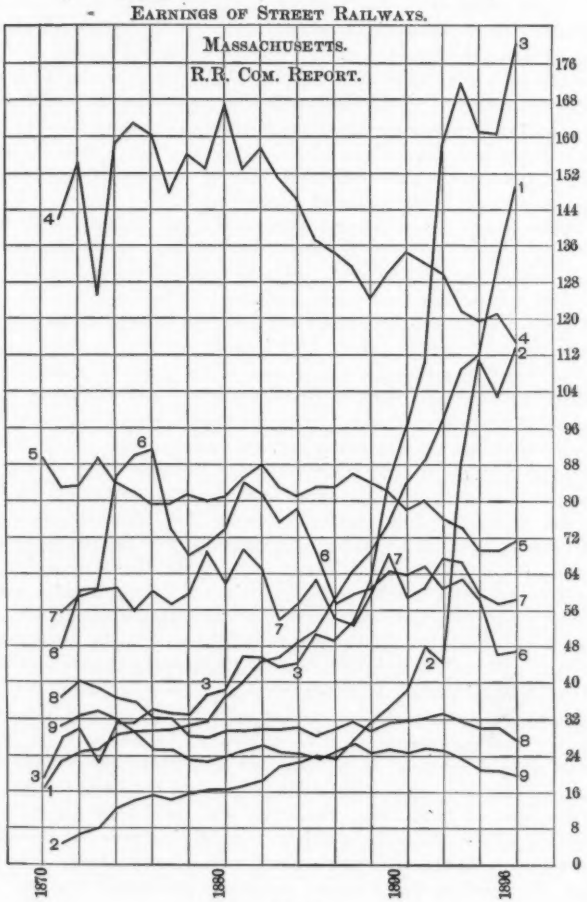

FIG. 4.

Mr. Davis. character of city and country, etc., would be the same in either of the cases under discussion for any specific example. The cost of clearing, grading, ditching, tunnels, masonry, culverts, fencing, cattle-guards, and those parts of the system pertaining to these general items, is not affected by the choice of system. It might be thought, at first, that the cost of masonry would be affected if lighter bridges and trestles could be used with electric traction, but the weight and size of masonry abutments, piers, footings, etc., would hardly be affected by any slight changes in the moving load, for they are much more dependent upon the weight of the earth embankment which they support and the character of the ground upon which they are built, together with their height and length. If they perform all their other functions according to the best engineering practice, they will usually be found far more substantial than, theoretically, they need to be, in order to uphold the weight of the superstructure. Road crossings will be the same; (the additional cost of connecting a "broken" third-rail system being included under item 12.)

In the design of bridges and trestles, the principal elements which determine their cost are the span, dead weight, live uniform-load, concentrated live-load at head of trains (locomotive and tender), the speed of trains, and the "hammer-blow" of the reciprocating parts of a steam locomotive, especially when it coincides with the period of oscillation of a bridge (very objectionable on bridges which are too light). Electric motors, either geared to the axles or gearless (concentric with the axle), have a rotative motion, and therefore do not produce the "hammer-blow." Owing to the peculiar construction of the electric locomotive or motor car, a greater proportion of the total weight is on the driving wheels than is the case with steam locomotives; therefore, with the same tractive effect (weight on drivers), the use of electric locomotives or motor cars reduces the moving weight at the head of the train, and the weight of the tender is saved by the use of electricity. These three facts, theoretically, would enable bridges and trestles to be built lighter for roads using electric motors, providing the loads were not concentrated upon a smaller wheel base, were it not for the fact that the necessity of providing for constantly increasing weights practically offsets the theoretical saving which might be made. If motors were used on every car of the train, such structures might be designed so as to be lighter and less costly, but, for reasons stated, this is unlikely. In addition, if freight service should continue to be handled by locomotives on the same tracks or adjoining ones, lighter bridges would not be possible.

The cost of ballasting, ties, rails and track-laying, lining and surfacing will be the same in either case (drilling rails for bonding is covered by item 11), although a small saving in maintenance of these items is possible for electric traction (discussed under "total

Mr. Davis.

EXPLANATION.

Curve.		Multiplier for Vertical Scale.
1.	Gross Traffic Earnings, in Dollars	1 000 000
2.	Total Interest on Bonded Debt, in Dollars	100 000
3.	" Dividends on Capital Stock, in Dollars	100 000
4.	Gross Traffic Earnings per Mile of Track, in Dollars	100
5.	Percentage of Expenses to Gross Earnings	1
6.	" " Interest Paid on Bonded Debt	1/10
7.	" " Dividends " " Capital Stock	1/10
8.	Gross Earnings per Revenue Train-Mile, in Cents	1
9.	" Expenses " " " " " "	1
10.	Percentage of Passenger Earnings to Gross Earnings	1/2
11.	" " Freight " " " "	1/2
12.	" " Interest and Dividends paid on Capital Stock and Bonded Debt	1/10

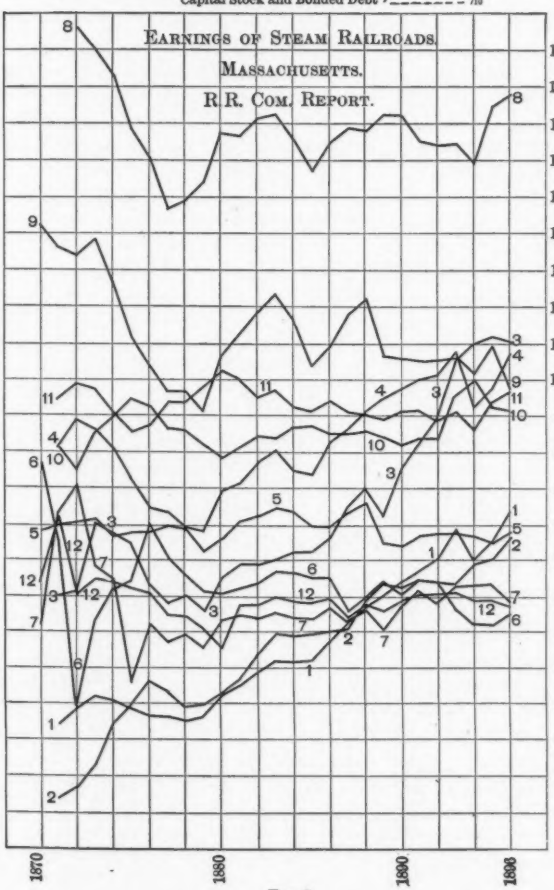

FIG. 5.

Mr. Davis. expense"), which indicates that the first cost could be reduced for the same cost of operating; yet, as this would be poor economy, the quality, weight and general character should be the same in either case. By the use of electricity it might, at first, appear that the signal and telegraph system would be reduced in first cost, but the only possible saving would be in the source of the current used, which forms so small a percentage of the whole that for our purposes any difference can be neglected.

Stations would cost the same under similar conditions, whether steam or electricity were used, although the electric road requires buildings for its centralized motive-power plant (that is, all but the transmission line and motors) which are not a burden on the steam road, yet these are no doubt balanced by round houses, coal stations, water stations and the larger machine shops required for steam locomotive repairs. Terminals will cost the same, whichever system is used.

So far, we have found that the first cost of construction is substantially the same, whether steam locomotives or electric motors are used, but, if the latter are adopted, some additional work is necessary, namely, (11) rail bonding and (12) overhead-trolley line or third rail. It will at once be seen that these items add considerably to the cost of construction of an electric road, as compared with that of a road operated by steam locomotives.

As an example, which will show, in a general way, the increased cost of electric-traction construction, let us assume, without any pretension to exactness, for each individual case will differ in the amount of increased cost, that the line is single track, one mile long; average speed of trains (including stops) 20 miles per hour; headway, one minute; length, six cars (one being a motor car); total weight of train, 200 tons when loaded to ultimate capacity; rails, 90 lbs. per yard; average nominal horse-power, 300 per train (will exert 450 H.-P., or even more, if required for short periods); total maximum average nominal horse-power per mile of track (one way) at above headway, 900; average loss in transmission, 20%; assumed average nominal horse-power at station, 1 125 (allowing for loss and including surplus power), located at one end of the line. With these assumptions, we have the following approximate additional cost for construction, if electricity is used. The electric return circuit would consist of the two lines of rail properly bonded with copper wires, two 4/0 B. & S. G. wires to each rail joint, which would cost (copper, 15 cents per pound), complete in place, including terminals and drilling rails, 70 cents each bond, or a total of $497. To this must be added the cross-bonding of the lines of rails, which varies much in practice. For our case we assume that this is unnecessary, if the bonds at the joints are properly made, and maintained with the care displayed on other parts of the system. The overhead-trolley line would be of iron

Mr. Davis.

EXPLANATION.

Curve.		Multiplier for Vertical Scale.
1.	Passenger Train-Miles (Car-Miles.)	1 000 000
2.	Total Passengers Carried	2 000 000
4.	Gross Passenger Earnings. (Same as Curve 1, Fig. 4).	
6.	Receipts per Passenger Carried, in Cents.	1/10
7.	" " " Train-Mile. (Same as Curve 8, Fig. 4).	
8.	" " Mile of Track. (Same as Curve 4, Fig. 4).	
9.	Number of Passengers Carried per Mile of Track.	2 000
11.	Passenger Rides per Capita per Annum	1
12.	Receipts per Capita per Annum, in Dollars	1/10

PASSENGER TRAFFIC OF STREET RAILWAYS.

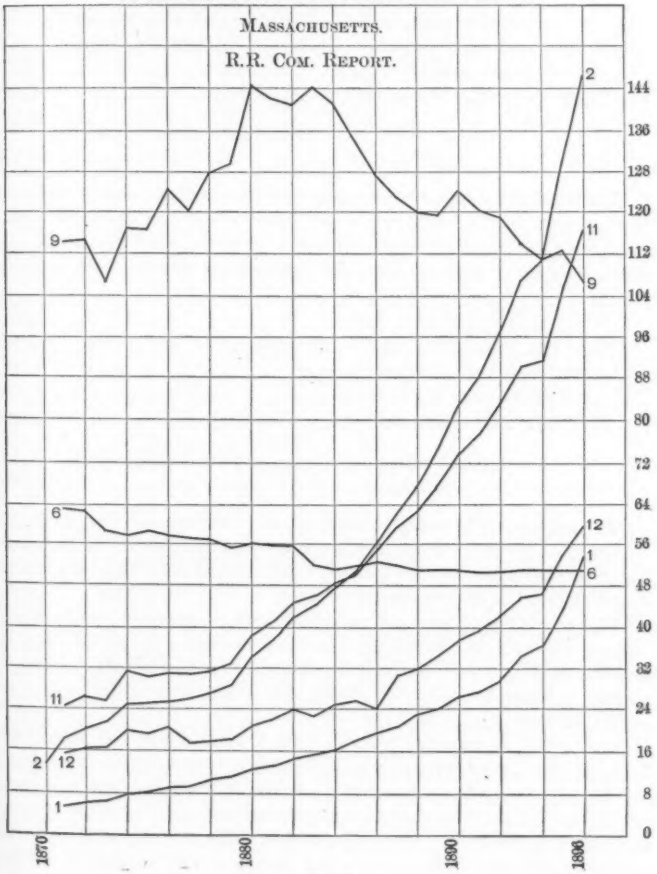

FIG. 6.

Mr. Davis. poles, center-construction (assuming that there would be a double track); trolley wire 423 200 circular mils; poles set every 100 ft., each weighing 1 300 lbs. (30 ft. by 8 ins. and 7 ins. and 6 ins.) set in concrete, would cost for one mile, approximately, $3 237 (one-half of poles with brackets and feeder supports, etc., set at $50 each; trolley 6 748 lbs., at 15 cents; special line material, $500; labor, $400).

To recapitulate: One mile of track equipped electrically will cost:

(11) Rail bonding. In this case the cost of ground-return circuit is not an extra cost against the electric road, for the rails are used, they having sufficient capacity to carry the current. (See Equipment)	$497
(12) Overhead-trolley line	3 237
Total extra per mile for electric trolley railroad	$3 734

If a third-rail system were used, which is probable where the road is on its own right-of-way and where high speeds and frequent service are necessary together with longer and heavier trains than the single cars of a railway system, then the increased cost would be approximately:

(11) Rail bonding, as before	$497
(12) 70.7 tons 90-lb. third-rail, special section, at $30	2 121
528 treated wooden supports at $1	528
176 joints to bond, at $3	528
Laying, at 5 cents per foot	264
Total extra per mile for third-rail electric railroad	$3 938

The apparent difference in favor of the overhead trolley must not be assumed to exist generally; accidentally, it happens to be less in the first case than in the second, while usually, on long lines with dense traffic, the reverse would be true.

There being no items applicable exclusively to steam railroads, to balance (11) and (12), it is seen that the first cost of construction of an electric road will be greater and that this increase will amount to several thousand dollars per mile of track, depending upon the conditions existing in each case.

Under (c) "Equipment," if the road is to be equipped to operate freight trains by electric power, there are two possible ways of doing so; first, by using the present style of freight cars and hauling them by electric locomotives; or second, by equipping each car with motors, thus making each an independent unit. The latter would only be feasible could the units be coupled together and controlled at the

Mr. Davis.

EXPLANATION.

Curve.		Multiplier for Vertical Scale.
1.	Passenger Train-Miles	1 000 000
2.	Total Passengers Carried	1 000 000
3.	Passengers Carried one Mile	10 000 000
4.	Gross Passenger Earnings, in Dollars	1 000 000
5.	Receipts per Passenger per Mile Carried, in Cents	1/10
6.	" " " Carried, in Cents	1
7.	" " " Train-Mile, in Cents	1
8.	" " Mile of Track, in Dollars	100
9.	Number of Passengers Carried per Mile of Track	100
10.	Miles Traveled per Passenger	1/4
11.	Passenger Rides per Capita per Annum	1
12.	Receipts per Capita per Annum, in Dollars	1/10

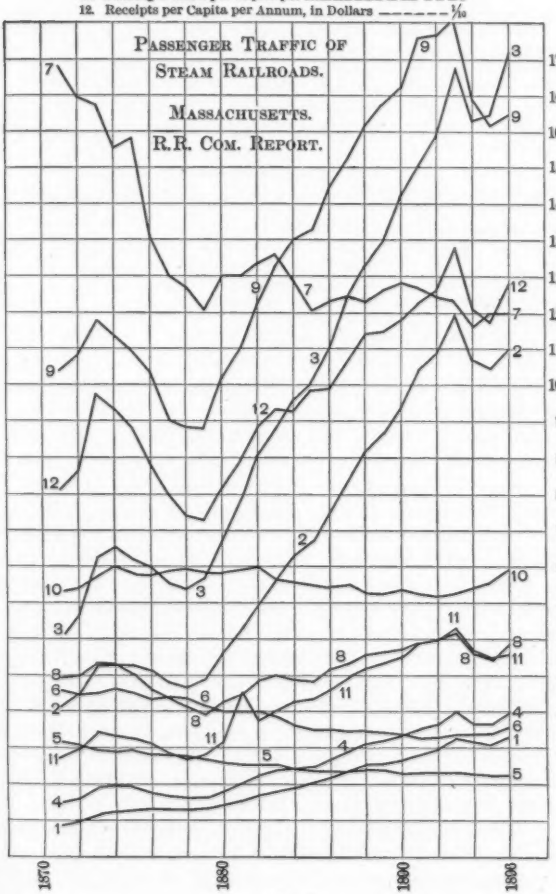

FIG. 7.

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EXPLANATION OF FIG. 8.

Curve.	Multiplier for Vertical Scale.
Curves Deduced from Fig. 2.	
1. Total Miles of Track	100
2. Annual Increase of Mileage	100
3. Total Capital Stock, in Dollars	500 000
4. " Bonded Debt, " "	500 000
5. " Capitalization, " "	1 000 000
6. " " per Mile of Track Owned, in dollars	500
Curves Deduced from Fig. 4.	
1. Gross Traffic Earnings, in Dollars	1 000 000
2. Total Interest on Bonded Debt, in Dollars	100 000
3. " Dividends on Capital Stock, in Dollars	100 000
4. Gross Traffic Earnings per Mile of Railroad, in Dollars	100
5. Percentage of Expenses to Gross Earnings	1
6. " " Interest Paid on Bonded Debt	$\frac{1}{10}$
7. " " Dividends Paid on Capital Stock	$\frac{1}{10}$
8. Gross Earnings per Revenue Train-Mile (Car-Mile) in Cents	1
9. " Expenses " " " " " " " "	1
Curves Deduced from Fig. 6.	
1. Passenger Train-Miles (Car-Miles)	1 000 000
2. Total Passengers Carried	10 000 000
4. Gross Passenger Earnings (Same as Curve 1, Fig. 4)	.....
6. Receipts per Passenger Carried, in Cents	$\frac{1}{10}$
7. " " " Train-Mile (Same as Curve 8, Fig. 4)	.....
8. " " Mile of Railroad (Same as Curve 4, Fig. 4)	.....
9. Number of Passengers Carried per Mile of Railroad	10 000
11. Passenger Rides per Capita per Annum	1
12. Receipts per Capita per Annum, in Dollars	$\frac{1}{10}$

head of the train; but imagine interchanging and making up a train of 50 to 100 cars arranged in this way by any present known mode of electric equipment, control and propulsion; no arguments seem necessary to show the folly of attempting it to-day. The only feasible method is evidently by electric locomotives at the head of such trains. The best practical example of this mode of operation is given in the Baltimore Tunnel of the Baltimore and Ohio Railroad, where 100-ton electric locomotives haul freight and passenger trains, together with their steam locomotives. They do the work satisfactorily, but the writer has seen no claims advanced to show that they are economical; in fact, the only defence for their use is one of cleanliness and ventilation in the tunnel, which is more satisfactory to passenger traffic, and undoubtedly attracts and stimulates it. The installation cost, if the writer's memory serves, over $2 000 000 for a few miles of track; so that the interest on this sum is much more than enough to offset any saving in operation, if even the latter can be shown. This is extremely doubtful. Such an investment could not be justified on any grounds if only freight were handled, although it may be by an increase in the passenger traffic. Freight trains are slow-moving, heavy units, requiring large powers constantly applied, and are run at comparatively infrequent intervals. The effort of all steam railroad man-

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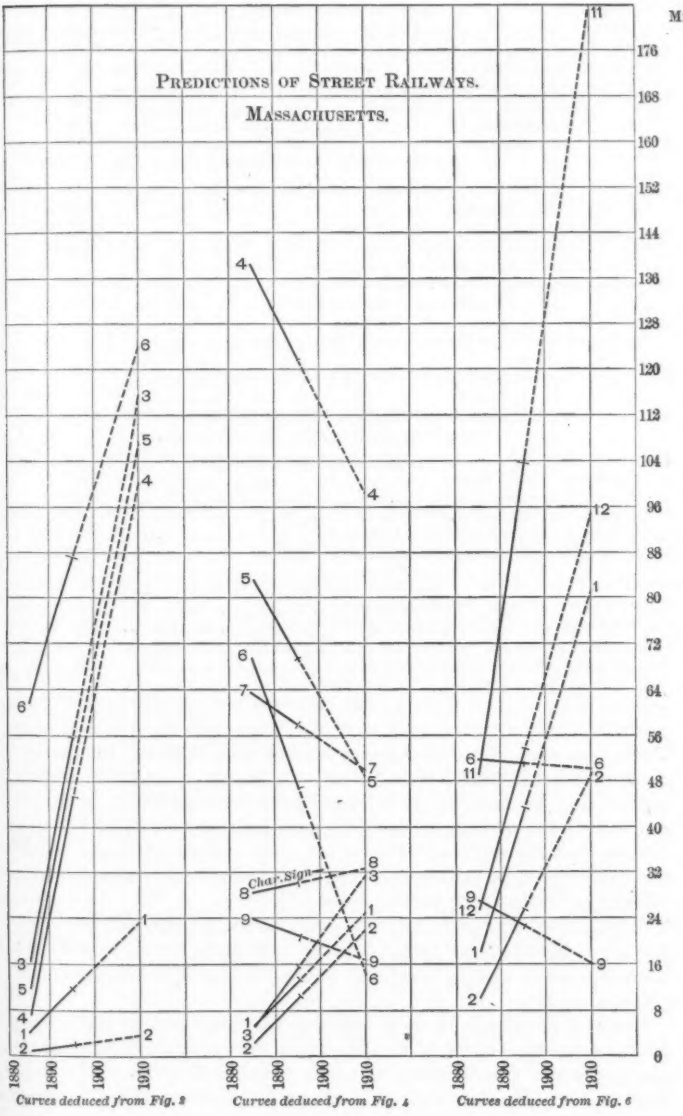

FIG. 8.

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EXPLANATION OF FIG. 9.

Curve.	Multiplier for Vertical Scale.
Curves Deduced from Fig. 3.	
1. Total Miles of Track	100
2. Annual Increase of Mileage	10
3. Total Capital Stock, in Dollars	10 000 000
4. " Bonded Debt, " "	1 000 000
5. " Capitalization, " "	10 000 000
6. " " per mile of Railroad, in Dollars	1 000
Curves Deduced from Fig. 5.	
1. Gross Traffic Earnings, in Dollars	1 000 000
2. Total Interest on Bonded Debt, in Dollars	100 000
3. " Dividends on Capital Stock, in Dollars	100 000
4. Gross Traffic Earnings per Mile of Railroad, in Dollars	100
5. Percentage of Expenses to Gross Earnings	1
6. " " Interest Paid on Bonded Debt	$\frac{1}{10}$
7. " " Dividends " " Capital Stock	$\frac{1}{10}$
8. Gross Earnings per Revenue Train-Mile, in Cents	1
9. " Expenses " " " " "	1
10. Percentage of Passenger Earnings to Gross Earnings	$\frac{1}{2}$
11. " " Freight " " " "	$\frac{1}{2}$
12. " " Interest and Dividends Paid on Capital Stock and Bonded Debt	$\frac{1}{10}$
Curves Deduced from Fig. 7.	
1. Passenger Train-Miles	1 000 000
2. Total Passengers Carried	10 000 000
3. Passengers Carried One Mile	100 000 000
4. Gross Passenger Earnings, in Dollars	1 000 000
5. Receipts per Passenger per Mile Carried, in Cents	$\frac{1}{10}$
6. " " " Carried, in Cents	1
7. " " " Train-Mile, in Cents	1
8. " " Mile of Railroad, in Dollars	100
9. Number of Passengers Carried per Mile of Railroad	1 000
10. Miles Traveled per Passenger	$\frac{1}{4}$
11. Passenger Rides per Capita per Annum	1
12. Receipts per Capita, per Annum, in Dollars	1

agers is to increase train-loads, so as to decrease expenses per train-mile. If we apply the following argument and figures, changing the example to moving heavy freight trains, it will be seen at once that such traffic cannot now be handled by electric locomotives, involving heavy line work and large central stations (idle most of the 24 hours), for the main reason that interest on first cost will more than offset the largest possible saving in expenses. This saving would not exist, but if it should, more than 50% would be needed.

Passenger cars would cost the same in either case, as the cost of installing electric lighting and heating systems in the cars would balance the present gas lighting and steam heating systems of railroad passenger cars.

Should motor cars be used, carrying passengers, there would be a saving equal to the cost of one passenger car per train in favor of the electric road. If an electric locomotive were used, there would be no such saving. If every car were a motor car, then the cost of a steam

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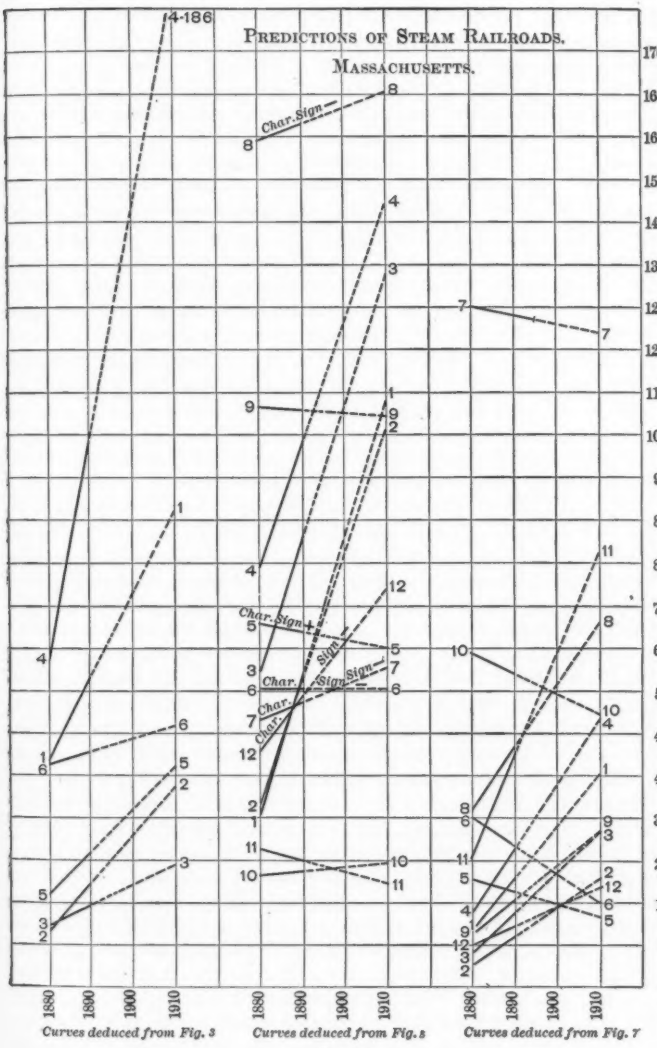

FIG. 9.

Mr. Davis. locomotive per train would be saved in the case of electric traction; this, however, would add to the cost of each car. This method is not satisfactorily solved to-day, although short trains are operated with more or less success.

Steam locomotives and tenders are to steam roads what motor cars (or electric locomotives), electric-feeder lines and ground-return circuits, and central power stations (without buildings) are to electric railways. To show the relative costs, let us again consider the former example. The feeder line would be about two 4/0 B. & S. G. wires of bare copper, as the company owns the right-of-way and crossings of public highways at grade are unlikely on roads of the character we are discussing; these would cost, in place, $1 117 ($1 012 for copper and $105 for stringing). It will be noticed that the trolley wire suggested is much larger than that used in general practice, and, as it has large carrying capacity, part of its cost might have been included in the cost of feeders. If the third rail were used in place of an overhead trolley, as explained before, this feeder system would be unnecessary, as the 90-lb. third rail when properly bonded has enough section to carry the current.

In our example the area of copper in the overhead system is 846 400 circular mils, equivalent to 920 mils diameter, which gives a total cross-section of 0.657 sq. in. A 90-lb. rail has a sectional area of 9 sq. ins. Taking the relative conductivity of steel and copper as 1 to 6, we find that each rail is equivalent to 1.5 sq. ins. of copper, and both rails to 3 sq. ins.; therefore, until the overhead system had a cross-section of more than 3 sq. ins., there would be no necessity for any copper ground-return circuit, so long as the bonding section at the joints was the same as that of the overhead work. In case the area of both rails divided by 6 is less than the area of overhead copper, the copper ground-return wire should be of a section equivalent to the excess in section of overhead copper. This ground return can be run on the pole line and connected down to the rails at intervals, or along the track, as may seem best in any given case.

The central power station of 1 125 nominal H.-P. could be erected complete (without buildings, included under "construction") for $50 per H.-P., which would provide a plant of the most modern kind, giving the greatest economy (in the largest sense). In general, it would consist of a steel stack lined with fire-brick, water-tube boilers, pumps, piping, condensers, heaters, blowers, direct-connected Corliss engines, direct-connected generators, slate switchboards, best indicating and recording instruments, etc., with all the best labor-saving and automatic devices which help to make a thoroughly successful plant. The total cost of the power plant would be $56 250. We will not discuss the use of an electric locomotive, but assume the use of motor cars drawing trailers, as it would only make a small difference

in the total amount given in the example. The figures, in any case, are only indicative. The same can be said of equipping each car as a motor car. Mr. Davis.

In the estimate of 200 tons as the weight of a 6-car train, one being a motor car, the car bodies assumed are 45 ft. over sills and 51 ft. over all, with two trucks having four wheels each, the wheels being 33 ins. in diameter; car body weighing 22 000 lbs.; trucks, 13 000 lbs.; total, 35 000 lbs.; average maximum passengers, 150 at 150 lbs. each, 22 500 lbs.; making the total weight of the passenger car loaded 57 500 lbs. The motor car is assumed to have four motors, one on each axle or geared to it, its total weight loaded being 112 500 lbs. (56.25 tons loaded, 45 tons empty, all on drivers). The trucks of this motor car would be heavier than those of the trail cars, and with larger wheels. With two four-wheel pivotal trucks, the weight on each driving wheel would be 14 082 lbs. loaded, or 11 250 lbs. empty. The complete trail cars can be assumed to cost, for steam or electricity, about $3 500; the complete motor car, about $7 000. A steam locomotive and tender of the same power and tractive force would cost about $9 000 (engine, $7 700; tender, $1 300). It will be noticed that the heating of cars has had no consideration herein. While this would add to the first cost of an electric system, by increasing the required capacity of transmission line and power house, and would undoubtedly add to the cost of operating as compared with steam-locomotive practice, yet available data are so unreliable that a discussion of them is postponed. To recapitulate: On the basis of our example, we see that items 2, 5 and 6 of the electric system of equipment leave only item 1 on the steam side of the ledger to balance them. It equalizes a small part only. The New York Central Railroad, in 1885, with 2 716 miles of single track, had $2 337 (5.7%) per mile invested in locomotives for passenger and freight service, and must have considerably more today. If we deduct investment for freight locomotives and compare with the following, it gives some idea of the difference in first cost of equipment against the electric system with only passenger service considered:

Feeder line	$1 117
Ground return (in this case no additional cost)	.....
Central power station	56 250
	$57 367
Deduct difference between 3 motor cars and 3 locomotives and tenders	6 000
Total extra per mile for electric trolley road	$51 367

To estimate a 10-mile road at ten times the above would be unfair, for, unless the train density remained the same on every mile and a power station were built for every mile, it could not be in direct pro-

Mr. Davis. portion. In general, the feeder system increases in cost with the distance, while the power station increases in cost with the weights moved and their speed. There would undoubtedly be found conditions of very light trains, at very frequent intervals, over short distances, where the larger cost of locomotives and tenders would balance the items which usually make electricity the more costly; these conditions must more nearly approach those which now exist in street railway service. It is evident that with units weighing 10 to 15 tons, run at intervals of 20 seconds to 5 minutes, any steam-locomotive system would prove undesirable, both by its greater first cost and operating expenses.

"Electric feeder lines and ground-return circuit" is placed under the heading "equipment" rather than under "construction" for the purposes of this discussion; in a system operated by electricity the opposite course would be pursued, and has been followed in considering "total expenses." "Central power stations" (all but buildings) would naturally be in the motive power department, and are so considered herein.

"General" items of "first cost" would be unaffected by the character of the system. A few years ago, when the word "electricity," as applied to street railways, was more attractive in banking and investing circles, higher prices for bonds might have been obtained by the use of that system, but elements of this kind are not within the scope of this discussion. Taxes are based on value, not on cost, and are therefore unaffected by any particular system.

Should an existing railroad change its motive power on all or a part of its system, the following items would represent the investment which would be made, the interest upon which must either be saved or earned to warrant it:

(*b*) CONSTRUCTION.

1. Engineering.
(Electric) 11. Rail bonding.
(Electric) 12. Overhead-trolley line or third rail.
15. Buildings for central power stations.

(*c*) EQUIPMENT.

(Electric) 2. Motor cars or electric locomotives.
3. Passenger cars (trail cars, or if motors are applied to every car).
(Electric) 5. Electric feeder lines and ground-return circuit.
(Electric) 6. Central power stations (not including buildings which are considered under "construction").

(*d*) GENERAL.

1. Discount on bonds.
2. Interest on bonds to opening of road.
3. Taxes to opening of road.
5. Contingent and miscellaneous, not itemized, to opening of road.

TABLE No. 2.—Cost of New York Central and Hudson River Railroad, 1885. Mr. Davis.

(2 716.05 miles of single track.)

Item.	Cost per mile of single track.	Percentage.
1. Grading and masonry	$7 749	18.9
2. Bridges, etc.	1 066	2.6
3. Superstructure	11 439	27.9
4. Stations, etc	5 453	13.3
5. Land and land damages	5 576	13.6
6. Locomotives	2 337	5.7
7. Passenger cars	574	1.4
8. Freight cars	5 576	13.6
9. Engineering	1 107	2.7
10. Floating equipment	123	0.3
Total	$41 000 (approx.)	100.0
11. Stock	$32 900	
12. Bonds	20 700	
Total capitalization	$53 600	

All other items would be unaffected on an existing system. Taking them up in detail:

Engineering expenses would not be as great as in the case of a new line. Items 11 and 12 under (*b*) "Construction," are applicable to this case, as already discussed for new lines. Buildings for power stations would be an additional cost, unless steam locomotives were entirely discarded and old round houses utilized; this, however, is hardly likely. Under practically all circumstances steam locomotives and tenders would be utilized on other parts of the system or for freight service, and therefore no allowance need be made for abandoning them. Items 2 and 3 under (*c*) "Equipment" should be new, and old equipment used elsewhere. Any attempt to use existing trucks or car bodies, either for motor cars or trailers, would be as bad a mistake as was made in the early days of the change from horse to electric traction on street railways. Items 5 and 6, under the same heading, are also applicable to this case, as already discussed for new lines. Items 1, 2, 3 and 5, under (*d*) "General" would have to be charged against the change, in proportion to the cost of the same. For all practical purposes, the total cost of a change of system is seen to be about equal to the difference in cost of two new lines, as follows:

(*b*) Construction	$3 734	per mile of track.
(*c*) Equipment	51 367	" "
(*d*) General (15%)	8 265	" "
Total	$63 366	" "

Mr. Davis.

TABLE No. 3.—ELECTRIC SUBURBAN AND

NAME OF RAILWAY.	Index No. of Ry.	Total passengers carried per annum; year ending June 30th, 1898.	Total length of single track operated miles).	Percentage of operating expenses to gross earnings.	Total passengers carried per mile of single track operated.	Total car-miles operated per annum.
MAINE (19 roads).						
Augusta, Hallowell & Gardiner Railroad	S 1	816 115	7.00	53	116 588	201 534
Bangor, Orono & Old Town Railroad.	S 2	1 225 028	17.40	88	73 414	408 570
Biddeford & Saco Ry.	S 3	337 860	5.72	67	58 984	136 312
Lewiston & Auburn Horse R. R.	S 4	1 160 445	14.00	77	82 888	350 000(a)
Portland & Cape Elizabeth Ry.	S 5	1 095 666	11.52	67	90 600	128 945
Portsmouth, Kittery & York St. Ry.	S 6	812 220	15.20	58	54 748	250 000(a)
Rockland, Thomaston & Camden St. Ry.	S 7	960 578	16.64	62	57 727	268 609
Totals and averages.	7	6 407 912	87.48	74	73 249	1 743 970
CONNECTICUT (31 roads).						
Danbury & Bethel St. Ry.	S 8	823 669	10.58	60	77 851	244 533
Derby Street Ry.	S 9	712 344	5.89	56	120 958	154 275
Fair Haven & Westville R. R.	S 10	4 898 363	19.89	56	246 272	1 283 642
Hartford, Manchester & Rockville Tramway.	S 11	599 429	17.88	63	33 525	243 542
Hartford & West Hartford Horse R. R.	S 12	375 375	9.70	98	38 698	188 892
Meriden Electric R. R.	S 13	1 439 285	17.00	77	84 663	445 864
Norwalk Street Ry.	S 14	748 842	7.52	69	99 580	167 592
Norwalk Tramway.	S 15	816 113	17.52	78	46 466	302 608
Norwich Street Ry.	S 16	1 256 626	11.91	70	105 476	223 347
Torrington & Winchester St. Ry.	S 17	436 726	12.56	64	39 548	162 684
Bristol & Plainville Tramway.	S 18	543 082	7.34	84	73 978	145 629
Central Railway & Electric (New Britain)	S 19	1 434 105	16.55	75	86 713	338 403
Totals and averages.	12	14 143 909	154.34	67	91 641	3 901 011
MASSACHUSETTS (103 roads).						
Arlington & Winchester.	S 20	330 594	3.33	67	99 277	79 210
Athol & Orange.	S 21	602 227	6.88	63	87 533	114 075
Braintree & Weymouth.	S 22	992 063	11.88	65	83 507	267 335
Bridgewater, Whitman & Rockland.	S 23	546 485	12.68	75	43 098	220 363
Brockton, Bridgewater & Taunton.	S 24	1 353 082	21.07	58	64 200	490 006
Brockton & East Bridgewater.	S 25	364 512	9.22	75	39 531	105 528
Dartmouth & Westport.	S 26	551 674	13.73	70	40 163	337 232
Dighton, Somerset & Swansea.	S 27	775 266	16.78	71	46 188	282 591
Fitchburg & Leominster.	S 28	2 178 863	21.43	64	101 673	671 274
Gloucester, Essex & Beverly.	S 29	1 556 243	22.71	61	50 911	355 932
Greenfield & Turners Falls.	S 30	712 647	12.86	64	55 416	178 076
Haverhill & Amesbury.	S 31	1 408 722	26.04	65	54 098	433 833
Haverhill, Georgetown & Danvers.	S 32	477 268	6.13	75	77 858	143 160
Hingham.	S 33	907 648	19.38	74	46 801	291 842
Hoosac Valley (North Adams).	S 34	1 536 505	13.00	71	118 138	349 752
Interstate Consolidated (R. I.)	S 35	2 589 797	22.42	68	115 513	660 306
Leominster & Clinton.	S 36	856 817	11.46	58	74 733	248 306
Lowell, Lawrence & Haverhill.	S 37	8 981 702	64.82	56	138 572	1 741 291
Lowell & Suburban	S 38	7 679 147	64.77	61	118 545	1 938 352
Lynn & Boston.	S 39	29 063 234	153.83	57	188 928	5 800 287
Marlborough.	S 40	756 465	7.54	90	100 314	223 834

(a) Estimated.

INTERURBAN RAILWAYS (R. R. COM. REPORT). Mr. Davis.

PASSENGER EARNINGS.								
Per mile of single track operated.	Per car-mile operated (cents).	Per passenger per trip (cents).	Total per annum from passengers; year ending June 30th, 1898.	No. of passengers carried per car-mile operated.	Percentage of dividends paid; year ending June 30th, 1898.	Permanent investment per mile of single track owned; year ending June 30th, 1898.	Capital stock and debts per mile of single track owned; year ending June 30th, 1898.	Total operating expenses per car-mile operated (cents).
$5 802	20.15	4.97	$40 227	4.04	4.0	$26 982	$39 687	10.90
3 659	15.58	5.19	61 251	2.99	8.0	15 208	16 475	13.76
4 363	18.30	7.38	24 837	2.47	....	23 483	27 651	12.27
3 721	14.80(*a*)	4.48	51 815	3.31 (*a*)	....	29 605	31 985	11.51 (*a*)
3 795	43.31	5.09	54 782	8.49	1.0	52 977	55 637	28.81
2 736	16.42(*a*)	5.03	41 061	3.25 (*a*)	1.2	26 556	26 788	9.57 (*a*)
4 099	25.39	7.10	48 028	3.02	....	19 058	31 631	15.93
$3 680	18.46	5.02	$322 001	3.10	....	$28 839	$25 409	13.71
4 045	17.51	5.13	42 826	3.37	4.0	50 844	47 399	10.64
6 024	23.00	4.98	35 486	4.62	....	55 515	58 527	13.02
12 459	19.31	5.06	247 812	3.82	6.0	36 436	43 298	10.87
3 422	25.13	10.20	61 192	2.46	....	29 317	28 002	15.92
3 051	15.67	7.88	29 599	1.99	....	58 323	52 046	15.49
4 245	16.19	5.08	72 176	3.23	....	94 373	92 507	12.63
4 844	21.74	4.86	36 430	4.47	4.5	31 338	32 159	15.09
2 099	12.16	4.50	36 790	2.70	2.0	38 927	33 466	9.58
4 529	24.17	4.29	53 973	5.63	....	45 498	42 511	17.08
1 927	14.88	4.86	24 202	3.05	....	29 987	28 933	9.57
3 641	18.34	4.90	26 718	3.73	3.0	35 827(*b*)	31 460(*b*)	15.49
3 856	18.86	4.45	63 821	4.24	....	78 934(*b*)	65 123(*b*)	14.26
$4 736	16.17	5.16	$731 025	3.62	....	$49 553	$50 229	12.53
4 938	20.76	4.97	16 444	4.17	....	29 831	28 928	13.86
4 281	25.82	4.89	29 339	5.27	8.0	19 771	17 464	16.21
4 087	18.16	4.89	48 258	3.71	3.0	21 248	20 691	11.81
2 136	12.29	4.96	26 960	2.47	....	16 577	16 940	9.26
3 381	14.55	5.27	69 484	2.76	3.0	24 903	24 405	8.29
1 988	17.46	5.06	18 352	3.45	....	20 981	20 341	13.11
7 055	28.74	17.57	95 578	1.63	8.0	26 594	24 541	20.18
3 668	21.79	7.94	61 516	2.75	....	27 541	27 328	15.56
6 267	20.01	6.16	134 014	3.24	8.0	25 905	25 787	12.84
2 599	16.59	5.11	58 698	3.24	3.0	17 837	17 880	10.23
2 689	19.38	4.85	33 677	4.00	4.0	16 835	16 386	12.37
3 443	20.67	6.36	88 000	3.24	....	25 903	25 811	13.46
3 914	16.76	5.03	23 757	3.33	....	18 176	17 096	12.63
2 304	15.31	4.92	44 197	3.75	....	22 059	22 741	11.30
5 894	21.92	4.99	75 214	4.38	6.0	19 558	17 881	15.64
6 039	20.50	5.23	134 714	3.99	6.0	20 465	25 083	14.02
3 805	17.57	5.09	43 165	3.45	....	31 282	32 487	10.22
6 980	25.98	5.04	448 938	5.15	4.0	48 795	47 401	14.68
5 986	20.00	5.05	380 177	3.96	3.0	36 004	36 169	12.28
9 648	25.59	5.11	1 472 154	5.01	8.0	58 851	59 200	14.75
5 117	17.24	5.10	35 952	3.38	....	24 720	26 967	15.60

(*b*) Includes cost of electric lighting plant, which could not be separated.

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TABLE No. 3 (*Concluded*).—ELECTRIC SUBURBAN AND

NAME OF RAILWAY.	Index No. of Ry.	Total passengers carried per annum; year ending June 30th, 1898.	Total length of single track operated (miles).	Percentage of operating expenses to gross earnings.	Total passengers carried per mile of single track operated.	Total car-miles operated per annum.
Milford, Holliston & Framingham	*S* 41	1 668 831	20.34	60	82 051	465 991
Natick & Cochituate	*S* 42	1 089 877	11.00	84	99 080	257 772
Newburyport & Amesbury	*S* 43	1 139 652	18.38	92	62 015	320 056
Newton	*S* 44	1 827 120	15.78	67	115 743	465 458
Newton & Boston	*S* 45	1 098 486	13.82	71	79 468	456 530
Norfolk Central (Dedham)	*S* 46	712 551	6.52	72	109 337	185 583
Norfolk Suburban (Hyde Park)	*S* 47	1 972 521	10.95	77	180 188	423 986
Northampton	*S* 48	1 812 627	17.12	62	105 847	487 369
North Woburn	*S* 49	809 869	7.80	70	103 803	189 073
Providence & Taunton	*S* 50	673 714	14.92	36	45 149	99 983
Quincy & Boston	*S* 51	2 712 342	30.06	64	90 240	564 141
Reading & Lowell	*S* 52	332 530	11.84	93	28 085	146 373
Rockland & Abington	*S* 53	1 521 581	17.22	83	88 336	397 812
Rockport	*S* 54	567 164	8.16	69	69 505	146 377
Southbridge & Sturbridge	*S* 55	552 586	7.75	68	71 320	149 588
South Middlesex (Natick)	*S* 56	1 134 670	13.07	63	86 815	269 181
Taunton & Brockton	*S* 57	949 244	17.23	76	55 093	249 362
Wakefield & Stoneham	*S* 58	1 129 681	15.30	58	73 835	374 431
Warren, Brookfield & Spencer	*S* 59	966 236	19.22	61	50 275	288 827
Worcester & Blackstone Valley	*S* 60	281 043	6.92	82	40 665	110 098
Worcester & Marlborough	*S* 61	1 229 738	17.36	65	70 837	342 877
Worcester & Suburban	*S* 62	3 275 611	21.91	68	149 483	714 529
Totals and averages	43	91 288 034	864.63	64	105 567	22 037 982
(*c*) *Totals and Averages of Table No. 3.*						
Maine	(*d*) 7	6 407 912	87.48	74	73 249	1 743 970
Connecticut	(*d*)12	14 143 909	154.34	67	91 641	3 901 011
Massachusetts	(*d*)43	91 288 034	864.63	64	105 567	22 037 982
Totals and averages	(*d*)62	111 839 855	1106.45	65	101 079	27 682 963

(*c*) Railways in Rhode Island, New Hampshire and Vermont are not treated in this table.

It should be remembered that the figures at the foot of page 875 are not exact, nor would it be fair to multiply by the number of miles of track equipped.

It is evident that, whether a new line be built under the same conditions of existing steam railroads, or an old system be changed over, the first cost will be against electric motive power; and to overcome this disadvantage the operating expenses must be reduced sufficiently to more than take care of the interest on this additional cost; or else the change must create an increased traffic which justifies it.

Wellington* gives a table showing the distribution of first cost of the New York Central and Hudson River Railroad in 1885, from which Table No. 2 has been calculated.

* "Economic Theory of Railway Location," p. 71.

INTERURBAN RAILWAYS (R. R. COM. REPORT). Mr. Davis.

PASSENGER EARNINGS.								
Per mile of single track operated.	Per car-mile operated (cents).	Per passenger per trip (cents).	Total per annum from passengers; year ending June 30th, 1898.	No. of passengers carried per car-mile operated.	Percentage of dividends paid; year ending June 30th, 1898.	Permanent investment per mile of single track owned; year ending June 30th, 1898.	Capital stock and debts per mile of single track owned; year ending June 30th, 1898.	Total operating expenses per car-mile operated (cents).
$4 103	17.91	5.00	$83 283	3.58	....	$20 096	$19 351	10.73
5 044	21.53	5.09	55 070	4.22	6.0	11 463	10 580	18.21
3 259	18.71	5.26	56 982	3.56	....	29 847	31 166	17.16
6 069	20.58	5.24	91 465	3.92	8.0	33 830	32 239	13.83
4 729	14.32	5.95	54 322	2.40	5.0	40 179	39 545	10.20
5 437	19.09	4.97	35 351	3.88	....	26 919	19 487	13.81
9 079	23.44	5.04	98 998	4.65	7.0	25 322	24 989	18.05
5 391	18.94	5.09	89 466	3.71	8.0	22 965	21 778	11.82
5 234	21.60	5.04	40 690	4.28	....	26 302	27 622	15.13
2 382	35.56	5.28	35 456	6.73	....	30 302	28 821	12.86
4 515	24.06	5.00	128 857	4.80	3.5	22 225	20 806	15.53
1 413	11.44	5.03	16 588	2.27	....	13 074	13 685	10.63
4 521	19.58	5.12	75 315	3.80	6.0	16 103	15 937	16.37
3 484	19.42	5.01	28 358	3.87	6.0	16 888	15 602	13.52
3 595	18.63	5.04	27 177	3.02	5.0	16 116	15 842	12.74
4 370	21.22	5.03	56 517	4.21	6.0	19 797	19 189	13.39
2 824	19.51	5.13	48 510	3.80	6.0	16 323	16 149	14.78
4 056	16.58	5.49	61 838	3.01	5.0	25 291	25 163	9.59
2 510	16.17	4.99	48 041	3.34	....	17 662	17 204	10.23
2 033	12.78	5.00	14 070	2.55	....	12 867	12 671	10.44
3 780	19.14	5.34	64 787	3.58	6.0	26 690	25 453	12.48
7 044	21.60	4.71	152 402	4.58	4.0	37 364	38 688	14.63
$5 437	21.33	5.15	$4 702 191	4.14	....	$30 131	$30 507	13.74
Electric Suburban and Interurban Railways.								
$3 680	18.46	5.02	$322 001	3.10	....	$28 839	$25 409	13.71
4 736	16.17	5.16	731 025	3.62	....	49 553	50 229	12.53
5 437	21.33	5.15	4 702 191	4.14	....	30 131	30 507	13.74
$5 201	20.79	5.14	$5 755 217	4.04		$32 738	$32 855	13.20

(*d*) No. of roads taken in each State.

From Table No. 3 we find that the average cost per mile of single track of 62 suburban and interurban electric railways in New England is $32 738, while the highest is $58 851, and the lowest $11 463. Obviously, it would be unfair to compare the steam railroad chosen with the foregoing average, as the former must exceed the average of its own class by over 25 per cent. Adding this percentage to the foregoing average gives approximately $41 000 per mile of single track as a fair comparative cost for an electric interurban railway with the same standard of construction and equipment as the New York Central and Hudson River Railroad. The construction account of such railways is about 50% of the whole; the equipment 30% (including power stations); and lands, buildings and other permanent investment about 20 per cent. From the foregoing, Table No. 8 has been computed.

Mr. Davis.

TABLE No. 4.—ELECTRIC CITY

NAME OF RAILWAY.	Index No. of Ry.	Total passengers carried per annum; year ending June 30th, 1898.	Total length of single track operated (miles).	Percentage of operating expenses to gross earnings.	Total passengers carried per mile of single track operated.	Total car-miles operated per annum.
MAINE (13 roads).						
Bangor St. Ry	C 1	1 523 837	9.70	82	157 096	326 197
Bath St. Ry	C 2	451 907	4.25	66	106 331	103 395
Calais St. Ry	C 3	485 613	7.00	79	69 373	183 960
Portland Railroad	C 4	5 444 897	30.95	68	175 925	1 155 854
Totals and averages	4	7 906 254	51.90	72	152 336	1 769 406
CONNECTICUT (31 roads).						
Bridgeport Traction	C 5	4 108 260	52.60	51	78 107	1 454 638
Hartford Street Ry	C 6	8 886 229	56.64	69	156 889	2 228 932
Middletown St. Ry	C 7	401 948	7.30	73	55 061	102 801
New Haven St. Ry	C 8	3 093 458	26.80	60	115 427	883 731
New London St. Ry	C 9	666 844	6.96	74	95 810	137 841
Stamford St. Ry	C 10	618 845	11.05	97	56 004	226 263
Winchester Ave. (New Haven)	C 11	4 381 462	17.54	61	249 798	764 801
Waterbury Traction	C 12	2 515 116	12.18	58	206 495	435 431
Totals and averages	8	24 672 162	191.07	63	129 131	6 234 438
MASSACHUSETTS (103 roads).						
Boston Elevated	C 13	181 321 295	278.35	71	651 410	32 209 150
Braintree	C 14	944 064	14.26	80	66 204	267 364
Brockton	C 15	6 787 425	43.37	63	156 511	1 463 110
Commonwealth Ave. (Newton)	C 16	1 447 822	12.73	92	113 724	478 017
Framingham Union	C 17	636 673	6.36	60	100 137	111 966
Gardner Electric	C 18	341 038	4.34	82	76 569	77 126
Globe (Fall River)	C 19	6 027 700	29.09	62	227 842	1 280 612
Gloucester	C 20	1 369 961	11.25	67	121 774	283 601
Holyoke	C 21	4 233 900	30.56	67	138 535	1 107 962
Pittsfield Electric	C 22	1 318 035	10.10	65	130 537	260 900
Plymouth & Kingston	C 23	691 048	8.75	67	78 977	181 650
Springfield	C 24	11 611 232	61.60	74	188 479	3 133 475
Taunton	C 25	1 269 804	17.13	54	74 115	383 711
Union (New Bedford)	C 26	3 776 878	19.96	64	189 222	799 738
Wellesley & Boston	C 27	709 887	4.66	67	152 336	220 980
West Roxbury & Roslindale	C 28	1 460 920	10.26	66	142 307	323 023
Worcester Consolidated	C 29	10 637 221	41.81	73	254 388	2 121 402
Woronoco	C 30	485 636	7.08	92	68 554	257 497
Totals and averages	18	235 670 539	611.66	72	385 296	44 961 284
Totals and averages (omitting C 13)	17	54 349 244	333.31	71	163 059	12 752 134
NEW HAMPSHIRE (5 roads).						
Union St. Ry	C 31	592 567	7.50	96	79 008	178 740
Nashua St. Ry	C 32	954 333	14.46	80	65 928	400 353
Concord St. Ry	C 33	971 160	12.50	92	77 692	300 000 (a)
Manchester St. Ry	C 34	3 290 386	17.02	68	201 124	762 635
Laconia St. Ry	C 35	229 171	3.63	75	68 043	59 665
Totals and averages	5	6 037 617	55.11	77	109 555	1 701 393
(b) *Totals and Averages of Table No. 4*						
Maine	(c) 4	7 906 254	51.90	72	152 336	1 769 406
Connecticut	(c) 8	24 672 162	191.07	63	129 131	6 234 438
Massachusetts	(c) 17	54 349 244	333.31	71	163 059	12 752 134
New Hampshire	(c) 5	6 037 617	55.11	77	109 555	1 701 393
Totals and averages	(c) 34	92 965 277	631.39	69	147 237	22 457 371

(a) Estimated. Given in report as "96 000 estimated," which is obviously wrong.
(c) No. of roads taken in each State.

RAILWAYS (R. R. COM. REPORTS). Mr. Davis.

PASSENGER EARNINGS.								
Per mile of single track operated.	Per car-mile operated (cents).	Per passenger per trip (cents).	Total per annum from passengers; year ending June 30, 1898.	No. of passengers carried per car-mile operated.	Percentage of dividends paid; year ending June 30, 1898.	Permanent investment per mile of single track owned; year ending June 30, 1898.	Capital stock and debts per mile of single track owned; year ending June 30, 1898.	Total operating expenses per car-mile operated (cents).
$6 731	20.00	4.28	$61 932	4.67	....	$58 864	$46 974	16.60
5 063	20.56	4.70	21 190	4.37	2.5	40 592	40 976	13.66
3 221	12.63	4.78	22 964	2.64	...	28 571	30 097	10.06
9 761	26.13	5.54	300 237	4.71	6.0	34 712	34 265	17.95
$7 825	22.97	5.15	$406 323	4.46	....	$35 441	$34 016	16.63
4 581	16.56	5.86	241 007	2.82	....	73 998	74 349	8.56
7 734	19.65	4.92	438 069	3.99	3.5	46 913	41 569	13.60
2 520	17.90	4.57	18 402	3.91	....	32 420	35 943	13.18
5 401	16.38	4.67	144 755	3.50	....	70 898	65 992	9.93
4 454	22.49	4.64	31 003	4.84	5.0	54 963	52 986	16.83
2 726	13.31	4.86	30 122	2.74	....	27 841	27 899	12.95
9 388	21.53	3.76	164 666	5.73	8.16	57 452	40 766	13.30
9 644	26.98	4.67	117 469	5.78	3.0	75 016	87 857	15.59
$6 204	19.01	4.80	$1 185 493	3.95	....	$59 .29	$62 517	12.04
33 976	28.50	5.06	8 967 587	5.62	2.25	98 600	103 655	20.39
3 163	16.87	4.78	44 635	3.53	4.0	13 115	13 193	13.46
7 749	22.97	4.95	330 559	4.63	6.0	34 997	34 326	14.52
5 783	15.40	5.08	71 331	3.02	....	29 068	29 145	14.27
4 785	27.17	4.78	29 954	5.68	....	22 523	21 962	16.48
3 940	22.18	5.01	17 020	4.42	....	17 533	18 403	18.32
10 943	24.86	4.80	301 238	5.17	....	75 447	74 886	15 57
6 272	24.88	5.15	68 498	4.83	6.0	33 377	31 211	16 71
7 496	20.68	5.41	227 165	3.82	8.0	29 964	27 950	13.95
6 543	25.32	5.01	65 845	5.05	6.0	13 663	12 451	16.45
4 209	20.28	5.01	34 106	3.25	6.0	18 865	18 577	13.62
9 464	18.60	5.02	577 800	3.70	8.0	35 591	31 362	13.73
4 112	18.36	5.55	63 490	3.30	....	54 556	55 073	9.96
10 327	25.78	5.45	187 728	4.72	6.0	47 899	45 415	16.50
8 449	17.82	5.55	37 609	3.21	8.0	24 759	23 895	11.93
6 568	20.87	4.62	67 188	4.52	3.5	35 877	36 846	13.70
12 863	25.35	5.06	530 259	5.01	8.0	47 803	44 675	18.58
3 243	8.92	4.73	22 933	1.88	2.5	16 273	16 967	18.17
$19 038	25.89	4.94	$11 644 945	5.24	....	$63 794	$61 928	18.84
$8 002	20.99	4.92	$2 677 358	4.26	....	$37 854	$34 379	14.93
4 064	17.05	5.14	30 485	3.31	....	.....	33 333	16.43
3 709	13.39	5.62	53 640	2.38	....	27 181	27 662	10.75
3 969	16.54	5.10	49 626	3.24	6.0	.....	17 480	15.35
8 182	18.26	4.23	139 266	4.31	10.0	18 192	20 564	11.96
3 439	20.92	5.44	12 483	3.85	....	.....	13 774	15.83
$5 180	16.77	4.73	$285 500	3.55	....	$22 321±	$24 832	12.89
Electric City Railways (C 13 omitted).								
$7 825	22.97	5.15	$406 323	4.46	....	$35 441	$34 016	16.63
6 204	19.01	4.80	1 185 493	3.95	....	59 129	62 517	12.04
8 002	20.99	4.92	2 677 358	4.26	....	37 854	34 379	14.93
5 180	16.77	4.73	285 500	3.55	....	22 321	24 832	12.89
$7 213	20.28	4.89	$4 554 674	4.13	....	$42 579	$42 031	14 .11

(*b*) Railways in Rhode Island and Vermont are not treated in this table.

Mr. Davis.

TABLE No. 5.—ALL ELECTRIC RAILWAYS

	No. of roads in each State.	Total passengers carried per annum; year ending June 30th, 1898.	Total length of single track operated. (Miles.)	Percentage of operating expenses to gross earnings.	Total passengers carried per mile of single track operated.
Maine	19	14 651 165	182.80	71	79 054
Connecticut	31	39 272 306	387.01	65	101 478
Massachusetts	103	330 889 629	1 590.95	69	207 982
Rhode Island	9	39 979 695	154.88	60	258 133
New Hampshire (1896)	5	6 037 617	51.11	77	109 555
Vermont (1896)	5	1 637 262	27.14	..	.....
Totals and averages	172	432 467 674	2 393.89	67	182 726

TABLE No. 6.—TOTALS AND AVERAGES OF TABLE No. 3, ELECTRIC ELECTRIC CITY RAIL-

Maine	†11	14 314 166	139.38	73	102 698
Connecticut	†20	38 816 071	345.41	64	112 376
Massachusetts	†60	145 637 278	1 197.94	66	121 572
Rhode Island	....	.....	.....	..	.....
New Hampshire	†5	6 037 617	55.11	77	109 555
Vermont	....	.....	.....	..	.....
Totals and averages	†96	204 805 132	1 737.84	67	117 890

TABLE No. 7.—TOTALS AND

Table No. 3.—Electric Suburban and Interurban Railways (selected from total number in New England)	†62	111 839 855	1 106.45	65	101 079
Table No. 4.*—Electric City Railways (selected from total number in New England)	†34	92 965 277	631.39	69	147 237
Table No. 5.—All Electric Railways in New England (total number in New England making reports to R. R. Comms.)	†172	432 467 674	2 393.89	67	182 726
Table No. 6.*—Electric City, Suburban and Interurban Railways (selected from total number in New England)	†96	204 805 132	1 737.84	67	117 890

† No. of roads taken.

IN NEW ENGLAND (R. R. COM. REPORTS).

Total car-miles operated per annum.	Passenger Earnings.				No. of passengers carried per car-mile operated.	Percentage of dividends paid, year ending June 30, 1898.	Permanent investment per mile of single track owned; year ending June 30, 1898.	Capital stock and debts per mile of single track owned; year ending June 30, 1898.	Total operating expenses per car-mile operated. (Cents.)
	Per mile of single track operated.	Per car-mile operated. (Cents.)	Per passenger per trip. (Cents.)	Total per annum from passengers; year ending June 30, 1898.					
3 273 932	4 720	26.35	5.89	862 885	4.47	.....	29 331	32 263	18.18
10 323 464	5 253	19.45	5.14	2 018 986	3.80	.....	51 177	51 610	12.71
68 206 418	10 632	24.80	5.11	16 545 554	4.85	.....	43 229	44 958	17.11
.....	13 092	.....	5.07	2 027 693	.....	.....	.....	75 698	.....
1 701 393	5 180	16.77	4 73	285 500	3.55	.....	22 321	24 832	12.89
.....	.....	.....	.....	.....	.....	.....	20 362	30 033	.....
83 505 207	9 186	23.60	5.04	21 740 618	4.68	.....	42 717	46 453	16.52

SUBURBAN AND INTERURBAN ELECTRIC RAILWAYS, PLUS TABLE NO. 4, WAYS (*C* 13 OMITTED).

3 513 376	5 225	20.73	5.08	728 324	4.07	.....	31 297	28 614	15.14
10 135 449	5 548	18.91	4.93	1 916 518	3.83	.....	54 850	57 026	12.23
34 790 116	6 160	21.21	5.06	7 379 549	4.18	.....	32 196	31 585	14.18
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1 701 393	5 180	16.77	4.73	285 500	3.55	.....	22 321	24 832	12.89
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
50 140 334	5 932	20.56	5.03	10 309 891	4.08	.....	36 313	36 189	13.91

AVERAGES, TABLES NOS. 3, 4, 5 AND 6.

27 682 963	5 201	20.79	5.14	5 755 217	4.04	.....	32 738	32 855	13.20
22 457 371	7 213	20.28	4.89	4 554 674	4.13	.....	42 579	42 031	14.11
83 505 207	9 186	23.60	5.04	21 740 618	4.68	.....	42 717	46 453	16.52
50 140 334	5 932	20.56	5.03	10 309 891	4.08	.....	36 313	36 189	13.91

* *C* 13 omitted.

Mr. Davis.

TABLE No. 8.

Item.	N. Y. C. & H. R. R. R.		Electric Railway (Approximate).	
	Cost per mile of single track.	Per-centage.	Cost per mile of single track.	Per-centage.
1. Grading and masonry	$7 749	18.9	$2 050	5.0
2. Bridges, etc.	1 066	2.6	410	1.0
3. Superstructure	11 439	27.9	9 020	22.0
9a. Engineering (½)	554	1.35	410	1.0
A. Rail bonding	.....	.....	410	1.0
B. Overhead electric line	.....	.....	2 460	6.0
C. Paving	.....	.....	5 740	14.0
Total construction	20 808	50.75	20 500	50.0
4. Stations, etc.	5 453	13.3	.....	.....
5. Land and land damages	5 576	13.6	.....	.....
Total land and buildings	11 029	26.9	8 200	20.0
6. Locomotives	2 337	5.7	.....	.....
7. Passenger cars	574	1.4	8 200	20.0
8. Freight cars	5 576	13.6	.....	.....
9b. Engineering (½)	553	1.35	.....	.....
10. Floating equipment	123	0.3	.....	.....
D. Electric feeder line and ground return	.....	.....	4 100	10.0
E. Central power plants	.....	.....	4 100	10.0
Total equipment	9 163	22.35	12 300	30.0

From Table No. 8, we see that items *A*, *B*, 7, *D* and *E* constitute those which would be an increase in the cost of a new electric line under steam-railroad conditions, or to change an existing steam railroad; all other items have already been shown to be the same, although varying, as the table shows, in the case of a street railway. We therefore get an approximate general figure of $20 000 per mile of single track as the increased cost of the electric railroad. This figure should be treated with caution in any individual case, for it might be less or even exceeded by more than 100% under some circumstances, although it is approximately accurate as an average.

In either a new or an old line there is a limiting factor which sometimes precludes the possibility of using electric traction—the transmission of electric power from the station to the motor. Some problems show at once that, owing to the long distance and infrequent trains of great weight, electric transmission of power would be entirely too costly. Just where the line occurs is hard to define, as it depends upon distance, amount of power, frequency of trains, and their weight. A few years ago it was considered that about ten miles' radius was the limit for one power house; this was before the days of "boosters" and multiphase currents. The development in multiphase transmission has led many to believe that this would make it

possible to successfully operate trunk railroad lines by electric motors. The basis for this is the reduction of line cost by the use of high potentials and the utilization of cheap sources of power such as waterfalls; but it must be remembered that the problem is not solely a question of the original cost of power, but rather the concentration of power and its long-distance transmission coupled with a cheap source, *versus* operation by small isolated units—steam locomotives. Mr. Davis.

In the operation of railways, whether electric or steam lines, one requisite is that the speed of trains must be controlled by the operator; the variations of speed must be numerous, and the change from one to another must be sufficiently smooth to cause no discomfort to the passengers or excessive strain on any of the apparatus. The electric railway motor operating by direct current has long been used for this work with satisfactory results, and in its latest forms is sufficient and serviceable, under the rough usage to which it must necessarily be subjected.

With alternating-current motors the regulation of speed is more difficult. Until the recent development in "induction" motors, the so-called "synchronous" motor was the only type worthy of practical consideration. This type derived its name from the fact that of necessity it ran at the same speed as the generator which supplied it with current. Obviously, therefore, the speed could not be varied. Besides this, the "synchronous" motor would not start by itself under load. Hence it was unsuited for operating railway cars. The other form of alternating motor—the "induction" motor—is capable of speed-regulation to a limited extent, and is continually being improved, so that the future may see developments and improvements beyond our most sanguine expectations. Alternating-current "induction" motors have certain characteristics which would be of great advantage in railway work. The most important of these is the absence of the commutator. In other words, there is no electrical connection between the stationary parts of the "induction" motor and the armature or rotating part, and therefore, there is no exposed metal carrying current, and no sparking due to the use of brushes.

The use of multiphase currents has the following advantages:

(1) They allow some control of the speed of motors.
(2) They provide for starting motors when loaded, but not when over-loaded to the same extent as direct-current motors.
(3) They facilitate insulation.
(4) They overcome some of the effects of induction.
(5) They reduce the cost of conductors.

In short, the "induction" motor, like the "synchronous" motor, presents the difficulties of starting under loads as well as speed-control. The two-phase and three-phase "induction" motors have

Mr. Davis. overcome these difficulties to a certain extent, and they offer some improvements over direct-current motors.

(1) They require less attention.
(2) They give less trouble from dirt, dust or water.
(3) They have no commutator.
(4) They have no moving electrical contacts (except in special cases).
(5) There is less danger of burning out armatures.
(6) They require renewal of parts less frequently.

The disadvantages in their use can be summarized thus:

(1) They do not start readily with over-loads.
(2) Their speed cannot be controlled readily.
(3) Their efficiency is lower.

At present the disadvantages outweigh the advantages, in so far as the conditions of railway work are concerned.

It seems, therefore, that the direct application of alternating-current motors to railroad systems is not feasible to-day from a practical standpoint; mainly for the reason that they do not start under heavy over-loads and are not easily varied in speed over wide ranges.

Irrespective of the motors, however, the alternating current can be used indirectly in operating railway lines. The method, in brief, is to carry the alternating current from the power station to a point in close proximity to a section of the track. Here the current is changed from alternating to direct by means of the so-called rotary transformer, and then applied as direct current to the cars using direct-current motors with the usual devices for controlling the speed. This method of using the alternating current introduces an extra transformation with its concomitant loss, and its use is confined to cases where it is desired to transmit power from a distance. Alternating currents are better adapted than direct currents for transmitting power over long distances, because, with the use of the latter, we are now limited to comparatively low pressures, either in the generating plant (1 000 to 3 000 volts) or the motors (500 to 1 000 volts); while with the former we can "convert," and thus utilize, between the generator and the motor, higher pressures than would be safe at either end. In transmitting currents of electricity over long or short distances, there is a necessary loss in transmission, due to the power required to force the current through the wires. This loss is present in all circuits carrying a current of electricity in greater or less amount, depending upon the volume (amperes) of current (squared), and the quality, size and length of the wire. In cases where large currents are to be carried long distances, the loss is so increased that it requires special consideration. The principle involved in all long-

distance transmission lines is to increase the pressure (voltage) to as high a point as practicable. This is done because the same amount of power can thereby be transmitted, at a correspondingly reduced current requiring a smaller wire, at the same or less loss, since the power is represented by the product of the current and the pressure. Hence, by reducing the current, the energy lost in the line is reduced in proportion to the square of the current. By thus increasing the pressure and reducing the current, the original investment in the transmission line can be kept within reason, and the interest account reduced, as well as the loss of energy in the line. Mr. Davis.

The limit to which this process of reducing the loss in transmission can be carried depends upon our ability to insulate wires carrying high pressures. There is no difficulty in using an alternating current running at a potential of 1 000 to 2 000 volts; for these pressures are common in the outside mains of lighting companies supplying alternating current for incandescent lighting in cities and towns. For long-distance transmission, however, the pressure must be raised to at least 10 000. This is now done successfully in a number of cases. The Niagara Falls transmission line is operated at 11 000 volts, and it is the intention to increase this to 22 000 volts, if it has not already been done; while there are installations on the Pacific Coast where higher potentials are used. How soon higher pressures than those now used will become commercially practicable remains to be demonstrated by the development in the use of present electrical insulating materials, or the discovery of new. In order to obtain high pressures, an intermediate step is required between the generator and the line, known as the "step-up" transformer, and another at the other end of the lines, known as the "step-down" transformer. Generators are built at present to deliver not much more than 2 500 volts, and usually run from 1 000 to 2 000 volts. The "step-up" transformers take this voltage and raise it, for transmission, to 10 000 or 20 000 volts. At the other end of the line the voltage is reduced to the desired amount, in a similar manner, by a "step-down" transformer and then applied to the distributing lines, or to the rotary transformer, or to both, as the case may require. High insulation is therefore required from the "step-up" transformer along the transmission line to the "step-down" transformer. The required insulation is secured by special construction in the transformers, which are also filled with oil, and by insulators of special design attached to cross-arms and poles adapted for the purpose.

We therefore see:

(1) That the alternating-current motor of to-day cannot be applied directly to operating railroad trains, either on the axles of the cars, or at the head of the train as a locomotive, because of the difficulties in starting under load and in controlling the necessary variations in speed.

Mr. Davis. (2) That the alternating current can be applied indirectly to operating railways, because of the facility with which we can transform it to high potentials for long-distance transmission.

Whether it will pay to utilize a "cheap source" such as a waterfall, or concentrate the power into one station on the line of railroad, is, again, the question of balancing the interest account on the added investment for long-distance transmission lines, etc., by reduced operating expenses or increased receipts.

The reduction of first cost to a minimum consistent with work best suited for the purpose is of great importance in the construction of any line. No increase is justifiable, unless it will prove a profitable investment in itself; no decrease, however, is justifiable if the larger expenditure promises larger profit. Where expenditures can be decreased, without materially lessening immediate traffic or adding to operating expenses, such decrease should be made. The importance of this is seen when we remember that the fixed charges (interest on bonds and rentals) are really a part of the cost of manufacturing transportation—to borrow an expression from an eminent authority; they are, in fact, one of the largest items in the total cost of running a railway system; they increase in a somewhat faster ratio than the cost of the line, and are the same every year, whether business is good or bad; and we therefore emphasize the importance of reducing the first cost to the lowest amount consistent with true economy, and of increasing the traffic to its maximum, so that the fixed charges may be a smaller percentage of the gross receipts. It must be remembered, however, that the gross receipts are often enormously increased by extraordinary expenditures, in which case large investments may be warranted, such as terminals at or near large centers of population, shortening of line for moral effect and saving of time in competition, adopting new methods as an inducement to increased use, etc. An idea of the weight which should be given to this part of the subject will be had by the comparison in Table No. 9.

TABLE No. 9.

	Steam Railroads (U. S.)			Massachusetts Electric Railways.
	Average.	High.	Low.	Average.
Percentage of operating expenses...	65	70	55	69
Percentage of net receipts.....	35	45	30	31
Percentage of fixed charges.....	25	45	14	15
Percentage of profit.....	10	16	4	16

By examining Table No. 9, which is not supposed to show highest and lowest figures, but averages under ordinary conditions, we see the

importance of the item of fixed charges, and the importance, therefore, of reducing the first cost. Mr. Davis.

The importance of a reduction in first cost, consistent with true economy, is also clearly brought out by:

Fig. 2. Curve 6.—Showing rapid increase in capitalization per mile of track of railways (40% of which is bonded indebtedness, approximately).

Fig. 8. Curve 2-6.—Showing predicted increase in Curve 6 of Fig. 2.

Fig. 3. Curve 4.—Showing greater increase in bonded debt as compared with increase of mileage of railroads.

Fig. 9. Curve 3-4.—Showing predicted increase in Curve 4 of Fig. 3.

Table No. 10. Capitalization of Steam Railroads and Street Railways.—Curve 4. Total Bonded Debt 332% increase 1870–1890, as against 213% increase in mileage of the U. S.; and 240% increase in New York, New Jersey, Pennsylvania, Delaware and Maryland, against 84% increase in mileage; and 437% increase in Massachusetts against 205% increase of mileage. The increase of 500% in bonded debt of street railways of Massachusetts in the same period, against 544% increase of mileage, does not disprove the statement, for this apparent decrease is due to the phenomenal growth of street-railway mileage.

2. Total Expenses.

As first cost is against electric traction we must look to reduced operating expenses or increased receipts as justification for its use. Let us examine the former. Again refer to our tabulated divisions of "total expenses," etc.

We have adopted the title "total expenses" in a literal sense, including all expenses of every kind, so that the difference between "total expenses" and "gross receipts," if on the right side, would give the amount which can be considered the actual net earnings of the line. "Operating expenses," which are generally treated as the usual and ordinary expenses of the system, include "maintenance and renewal of way and works," "train expenses," "station, terminal, taxes and general expenses," and "accidents, loss and damages," but not "fixed charges," although the latter form a large percentage of the actual total expenses, and have become a necessity in our industrial and financial development. The operating expenses include many items which do not vary with the amount of business or the character of the alignment—such as salaries of leading officials; maintenance of way, works and parts of the system, against that deterioration which

TABLE No. 10.—(*Continued*).

	Capitalization of Steam Railroads and Street Railways:						Fig. 2.		Fig. 3.	
1	Total miles of track	+	213		84		544		205	
2	Annual increase in mileage	±		11	135		446		4	
3	Total capital stock	+	213		104		215		124	
4	" bonded debt	+	332		240		500		437	
5	" capitalization	+	266		155		248		200	
6	" " per mile of track	+	31		52		20		47	
	Earnings of Steam Railroads and Street Railways:						Fig. 4.		Fig. 5.	
1	Gross traffic earnings	+	167		70		400		150	
2	Total interest on bonded debt	+	280		162		715		235	
3	" dividends on capital stock	+	48		16		405		140	
4	Gross traffic earnings per mile of track	+	10		4			**4**	25	
5	Percentage of expenses to gross earnings	+	9		3			**12**		**4**
6	" " interest paid on bonded debt	−	**1***			14		25		15
7	" " dividends " capital stock	−		52		55		10	6	
8	Gross earnings per revenue train-mile	−		23				15		10
9	" expenses " " "	−		15				26		23
10	Percentage of passenger earnings to gross earnings	+	8		4				1	
11	" " freight " "	−		6		7				3
12	" " interest and dividends paid on capital stock and bonded debt	−		25					4	
	Passenger Traffic of Steam Railroads and Street Railways:						Fig. 6.		Fig. 7.	
1	Passenger train-miles	+	750		200		364		204	
2	Total passengers carred	+	766		900		507		308	
3	Passengers carried one mile	+	443		300				202	
4	Gross passenger earnings	+	152		71		400		120	
5	Receipts per passenger per mile carried	−		33		17				30
6	" " " carried	−		35		37		20		28
7	" " " train-mile	−		32		19		15		22
8	" " mile of track	+	30		3			**4**	55	
9	Number of passengers carried per mile of track	+	14		128			**24**	60	
10	Miles traveled per passenger	−		14		20				1
11	Passenger rides per capita per annum	+	300		300		204		100	
12	Receipts per capita per annum	+	58		22		146		50	

* Heavy type indicates that the percentage of increase or decrease has not followed the characteristic sign of the curve.

Mr. Davis.

TABLE No. 10.—PERCENTAGE OF INCREASE OR DECREASE OF STEAM RAILROADS AND STREET RAILWAYS FROM 1870 TO 1890.

Curve.	Items.	Characteristic sign of curve.	Steam Railroads. United States.		Steam Railroads. N. Y., N. J., Pa., Del., Md.		Street Railways. Massachusetts.		Steam Railroads. Massachusetts.	
			Per cent. Increase.	Per cent. Decrease.	Per cent. Increase.	Per cent. Decrease.	Per cent. Increase.	Per cent. Decrease	Per cent. Increase.	Per cent. Decrease.
	True Valuation of Real and Personal Estate:									
1	Total in the United States	+	117							
2	" " New York, New Jersey and Pennsylvania	+			44					
3	" " Massachusetts	+					33			
4	Per capita in the United States	+	33							
5	" " New York, New Jersey and Pennsylvania	+			0	0				
6	" " Massachusetts	+						16		
7	Percentage of increase in the United States	−		43						
8	" " New York, New Jersey and Pennsylvania	−				85				
9	" " Massachusetts	−						96		
	Population Statistics:		Fig. 1.		Fig. 1.		Fig. 1.		Fig. 1.	
1	Total miles of track	+	213							
2	Annual increase of mileage	±		11						
3	Total population of the United States	+	63							
4	Percentage of increase of the population of the United States	−		28						
5	Density of the population of the United States	+	60							
6	" " " " Massachusetts	+					53			
7	Total urban population of the United States (8 000 and up)	+	127							
8	Percentage of urban to total population of the United States	+	45							
9	Total population of New York, New Jersey and Pennsylvania	+			44					
10	" " Massachusetts	+					53			
11	" " New York City	+			60					
12	" " Brooklyn	+			83					
13	" " Philadelphia	+			55					
14	" " served by N. Y. & P. R. T. R. R., including New York, Philadelphia, Brooklyn, Newark, Jersey City, Camden, Hoboken, Elizabeth, Long Island City, and Richmond County	+			71					

Mr. Davis. is produced by time only, irrespective of the amount of business handled or work done; salaries of agents of all kinds, many of whom have to be employed whether business is large or small, etc. All of these might be called the "fixed operating expenses," and, as they often amount to nearly half of the total operating expenses, it will prove instructive and remunerative to keep railroad accounts so as to show this. To reduce the total expenses to the minimum consistent with true economy is as important as to reduce the first cost to the lowest amount, bearing the same axiom in mind.

We have two cases to consider and compare with steam-railroad operation: First, central steam-power plants located along the proposed line; second, water-power located at some distance from the line. The following applies to both cases, unless otherwise indicated:

"Repairs of earthwork to subgrade" would be unaffected by the system used. Repairs of track, fences, cattle-guards, crossings, etc., renewals of ties and ballast, are substantially independent of the volume of traffic; ties wear independently of the tonnage, for the so-called "cutting" of ties is due primarily to the rotting away under the rail foot, accelerated somewhat, but almost inappreciably, by the decayed material cut away by passing loads. The total cost of track labor is affected only by a very small percentage of the whole by any change in the amount of traffic, provided the standard of maintenance is not increased; rail-renewals, track-watchman, and part of the labor of lining, surfacing, etc., directly applicable to the track itself, are the only items which vary directly with the number of trains. One-half to three-fourths of the wear of steel rails is caused by the locomotive, and is due more to the great concentration of load on the driving wheels, which often nearly approaches the ultimate crushing resistance of the rail, than to the "hammer-blow" of the reciprocating parts. Maintenance of crossings would be unaffected by the system used. For the reasons enumerated above, items 2, 3, 7, 8 and 9 would be unaffected in cost of maintenance, whichever system were used. While some might claim that the renewal of rails would be less frequent on an electric system, it must be remembered that an electric locomotive or a motor car at the head of a train must have concentrated on the wheels the same weight for the same speeds and loads, the only advantage being the removal of the hammer-blow of reciprocating parts. Should motors be placed on every axle, there would be a saving. In steam-railroad practice this item amounts to about 4% of the total cost per train-mile (see Table No. 11), so that, should there be a saving of 25%, it would equal about 1% of the total cost per train-mile.

Maintenance of bridges and trestles should be slightly less with the use of electric motors, because of less vibratory effects; maintenance of masonry, buildings and signals would not vary in cost with change

of system. We find under "maintenance and renewal of way and works," that there are no items exclusively applicable to steam-locomotive practice; but there are six which apply to electric traction only. This arises naturally from the fact that these items occur under "first cost," and must be maintained. They are: maintenance of—(4) ground-return circuit, (5) overhead-trolley line or third rail, (6) electric feeder lines; and renewals to—(10) poles or insulation of third rail, (11) trolley or third rail and ground return, and (12) feeders. The maintenance and renewals of these constitute an increase in the total expenses of an electric road over those of a road operated by steam. Mr. Davis.

The additional expense of these items, on the basis of all Massachusetts street railways, is shown in Table No. 11. This is, of course, not strictly accurate, as they do not operate under like conditions, but the figures are indicative, so that, with proper consideration of this difference, they can be used:

(*e*) 4.	Repairs of ground-return circuit	0.50	per cent.
(*e*) 5.	" " overhead trolley	1.12	"
(*e*) 6.	" " feeder lines	0.60	"
(*e*) 10.	Renewal of poles for overhead trolley	0.30	"
(*e*) 11.	" " overhead trolley	0 20	"
(*e*) 12.	" " feeders	0.05	"
	Total	2.77	"

The probability is that these percentages are too low for the heavy powers and high speeds of an electric road operating under steam-railroad conditions.

The next division is that of (*b*) "Train Expenses." The relative consumption of coal by steam locomotives and electric motor cars or locomotives, while of importance, is not so large a percentage of the operating expenses as is often imagined. As a rule, the attempt to save in fuel account has had more attention on electric roads than was warranted, and has been made at the sacrifice of other and more important items.

Omitting results obtained from compound locomotives, the records of which are not yet as extensive as those for single expansion, but which should show an average saving of approximately 20%, it has been found that in steam-locomotive practice, of the character we are discussing, the coal consumption per passenger-car-mile (exclusive of engine) averages about 6.5 lbs. for cars weighing 20–25 tons on way-trains, or 30–35 tons on through trains, and that about an average of 1 lb. is added per car-mile for each 6 tons' added weight of car. The average coal consumption of a passenger engine (say 40–45 tons) is about 20 lbs. per locomotive-mile. If we assume six cars to a train, as per our example, we have 3.3 lbs. per car-mile for the engine and 9.8 lbs. per car-mile for the whole train, including engine. This conforms to present average practice of steam railroads.

Mr. Davis.

TABLE No. 11—Comparative Operating Expenses of Steam

Ordinary division of items in total expenses.	All Massachusetts Street Railways (Railroad Commission Reports, 1899). Total expenditures. (In nearest $1 000.)	Percentage of total operating expenses.	Operating expenses per car-mile.
(1)	(2)	(3) Per cent.	(4) Cents.
(a) *Maintenance and Renewal of Way and Works:*			
1. Repairs of earthwork to subgrade	$1 163 000 includes (1), (3), (4), (7), (8), (9), (13).	9.3	1.6
2. Repairs of track			
3. Repairs of fences, crossings, etc.			
(e) 4. Repairs of ground-return circuit			
(e) 5. Repairs of electric line (third rail or overhead trolley)	286 000 includes (6), (10), (11), (12), (15).	2.3	0.4
(e) 6. Repairs of feeder lines			
7. Renewal of rails			
8. " ties			
9. " ballast			
(e) 10. " third-rail supports or poles for overhead trolley			
(e) 11. Renewal of third rail or overhead trolley			
(e) 12. Renewal of feeders			
13. Repairs of masonry, bridges, trestles, etc.			
14. Repairs of buildings	91 000	0.7	0.1
15. " signals			
(e) 16. Removal of snow and ice	280 000	2.2	0.4
Totals	$1 820 000	14.5	2.5
(b) *Train Expenses:*			
(s) 1. Fuel for locomotives			
(e) 2. " central power stations	1 268 000 includes (3), (4), (14), (15).	10.2	1.7
3. Water supply			
4. Oil and waste			
(s) 5. Repairs of locomotives and tenders			
(e) 6. Repairs of electric motors (car equipment)	439 000	3.4	0.6
7. Repairs of passenger cars	727 000	5.8	1.0
(s) 8. " freight cars			
(s) 9. Use of foreign passenger and freight cars			
(s) 10. Locomotive services (wages)			
(e) 11. Motor car services (wages similar to 10 and 12 for steam railroads)	4 893 000 includes (12).	39.1	7.0
(s) 12. Passenger train services (wages)			
(s) 13. Freight train services (wages)			
(e) 14. Repairs of central power stations			
(e) 15. Central power station services (wages)			
Totals	$7 327 000	58.5	10.3

† Estimated.

RAILROADS AND ELECTRIC RAILWAYS, WITH ITEMS IN DETAIL. Mr. Davis.

Fair average percentage in steam railroad practice.	Percentage of operating expenses on Massachusetts Electric Street Railways by distributing Column 3 according to Column 5.	Probable average percentage of operating expenses all Massachusetts Electric Street Railways estimated from Columns 3, 5 and 6.	Proportion of percentage of operating expenses of steam railroads, Column 5, estimated for proposed railroad from Philadelphia to New York (N. Y. & P. R. T. R. R.), to operate in 30 to 35 minutes without intermediate stops.	Probable comparative increase or decrease in cost of operation by a change of motive power from steam locomotives to electric motors.		Operating expenses per car-mile Metropolitan Street Railway Company, New York City, 1899.
				Per cent. Increase.	Per cent. Decrease.	
(5) Per cent.	(6) Per cent.	(7) Per cent.	(8) Per cent.	(9)	(10)	(11) Cents.
1.5	0.6970	0.20	1.5	Unaffected.		.....
8.2	3.8130	4.50‡	5.0	"		0.20
0.3	0.1395	0.02	0.2	"		.....
.....	0.0005	0.50	—	0.50	.....	.....
.....	.....	1.12†	—	1.12	.....	0.29
.....	.....	0.60†	—	0.60	.....	.....
4.0	1.8600	2.50	2.0	.....	1.50	.....
3.0	1.3950	1.24	0.5	Unaffected.		.....
1.0	0.4650	0.30	1.0	"		.....
.....	.....	0.30†	—	0.30	.....	.....
.....	.....	0.20†	—	0.20	.....	.....
.....	.....	0.05†	—	0.05	.....	.....
2.0	0.9300	0.04	1.5	.....	0.05	.....
2.0	.....	0.70	2.0	Unaffected.		0.06
1.0	.....	0.03†	1.3	"		.....
.....	.....	2.20	.....	.....	.....	0.13
23.0	.....	14.50	.....	2.77	1.55	0.68
8.0	.....	.....	.....	.....	.....	.....
.....	.....	5.40	—	.....	2.60	0.98
0.6	.....	0.30	1.0	.....	0.30	0.14
1.0	.....	0.50	1.0	.....	0.50	0.06†
6.0	.....	.....	.....	.....	.....	.....
.....	.....	3.40	—	0.20	.....	0.475
3.0	.....	5.80	3.0	Unaffected.		1.285
6.0	.....	.....	.....	"		.....
2.0	.....	.....	.....	"		.....
7.4	.....	.....	.....	.....	.....	.....
.....	.....	39.10	4.0	Unaffected.		6.46
3.0	.....	.....	.....	"		.....
5.0	.....	.....	.....	"		.....
.....	.....	2.00	—	2.00	.....	0.06
.....	.....	2.00	—	2.00	.....	0.33
42.0	.....	58.50	.....	4.20	3.40	9.79

‡Includes paving.

Mr. Davis. TABLE No. 11 (*Concluded*).—COMPARATIVE OPERATING EXPENSES OF

Ordinary division of items in total expenses.	ALL MASSACHUSETTS STREET RAILWAYS (RAILROAD COMMISSION REPORTS, 1899).		
	Total expenditures. (In nearest $1 000.)	Percentage of total operating expenses.	Operating expenses per car-mile.
(1)	(2)	(3) Per cent.	(4) Cents.
(c) *Station, Terminal, Taxes and General Expenses:*			
1. Agents and station services (wages)	.....	.....	.....
2. Station supplies	.....	.....	.....
3. Telegraph	.....	.....	.....
4. Taxes	855 000	6.8	1.1
5. General officers and clerks	625 000 includes (2), (8).	5.0	0.6
6. Legal	119 000	0.9	0.1
7. Insurance	310 000	2.5	0.4
8. Stationery and printing	.....	.....	0.2
9. Agencies and advertising	.....	.....	.....
10. Contingent and miscellaneous, not included elsewhere)	827 000 includes (1), (3), (9).	6.6	1.1
Totals	$2 736 000	21.8	3.5
(d) *Accidents, Loss and Damages:*			
(s) 1. To freight	.....	.....	.....
2. " passengers	645 000 includes (3), (4).	5.2	0.8
3. " property owned	.....	.....	.....
4. " " not owned	.....	.....	.....
Totals	$645 000	5.2	0.8
(e) *Interest Account* (discounts and temporary loans)	523 000	.....	Total 17.1 cents per car-mile.
(f) *Fixed Charges:*			
1. Interest on bonded debt	$1 384 000	.....	.....
2. Rentals	1 280 000	.....	.....
Total	$2 664 000	.....	.....
(g) *Dividends*	2 076 000	.....	.....

STEAM RAILROADS AND ELECTRIC RAILWAYS, WITH ITEMS IN DETAIL. Mr. Davis.

Fair average percentage in steam railroad practice.	Percentage of operating expenses on Electric Street Railways by distributing Column 3 according to Column 5.	Probable average percentage of operating expenses all Massachusetts Electric Street Railways estimated from Columns 3, 5 and 6.	Proportion of percentage of operating expenses of steam railroads, Column 5, estimated for proposed railroad from Philadelphia to New York (N. Y. & P. R. T. R. R.), to operate in 30 to 35 minutes without intermediate stops.	Probable comparative increase or decrease in cost of operation by a change of motive power from steam locomotives to electric motors.		Operating expenses per car-mile Metropolitan Street Railway Company, New York City, 1898.
				Per cent. Increase.	Per cent. Decrease.	
(5) Per cent.	(6) Per cent.	(7) Per cent.	(8) Per cent.	(9)	(10)	(11) Cents.
13.0	3.81	0.09	3.0	Unaffected.		.....
3.0	2.08	0.90	0.5	"		.....
1.0	0.29	.....	1.0	"		.....
3.5	.....	6.80	3.5	"		.....
3.5	2.44	3.80	2.0	"		0.19
0.5	.....	0.90	0.5	"		....
0.3	.....	2.50	0.3	"		.....
0.7	0.48	0.30	0.2	"		.....
2.0	0.59	0.01	0.5	"		.....
6.5	1.91	6.50	6.5	"		0.76
34.0	.....	21 80	.....	.....	.....	0.95
0.3	.....	.....	.....	Unaffected.		.....
0.4	2.97	5.09	0.4	"		0.53
0.2	1.49	0.19	0.2	"		Included in (2).
0.1	0.74	0.01	0.1	"		Included in (2).
1.0	.....	5.20	.....	.....	.....	0.53
.....	.....	.....	.....	Unaffected.		Total 11.95 cents per car-mile.
.....	.....	.....	.....	Materially affected, estimated from 5 to 15% or more increase.		.....
.....	.....	.....	.....	Unaffected.		.....
.....	.....	.....	.....	Total percentage of increase 7.02% to 17.02%.		.....
.....	.....	.....	.....			.....

Mr. Davis. Table No. 12 shows the average amount of dry steam used per horse-power-hour by various types of stationary engines under different conditions. It is compiled from a large number of actual tests.

TABLE No. 12.—STEAM CONSUMPTION IN POUNDS PER HORSE-POWER-HOUR.

Type of engine.	STEADY LOAD.		VARIABLE LOAD 50 TO 125 PER CENT.		EXTREME VARIATIONS—RAILWAY WORK, ETC., 0 to 150 PER CENT.	
	Non-con.	Con.	Non-con.	Con.	Non-con.	Con.
High-speed, simple.....	32	28	34	30	36	31
High-speed, compound	23	18	25	21	27	22½
Slow-speed, simple..	25	21	28	23	31½	26½
Slow-speed, compound.....	20	15	22½	18	26	23
High-speed, triple expansion.	17½	13	20	16	.....	.....
Slow-speed, triple expansion.	14½	12½	17	15	.....	.....

Tables Nos. 13, 14 and 15 show the coal consumption per car-mile on electric railways, and were compiled from information obtained in 1894–95. Over 600 railways were communicated with, from which 58 have been selected as giving the most accurate results.

Table No. 13 gives the road by index number, the State where located, the car-miles, kind of boilers, engines and coal, the field from which coal was obtained, the long tons of coal used in the given fiscal year, and the pounds of coal consumed per car-mile.

Table No. 14 gives the average, highest and lowest pounds of coal per car-mile, grouping the roads by territorial sub-divisions and kinds of coal, with the number from which the averages have been calculated.

Table No. 15 gives the average, highest and lowest pounds of coal consumed per car-mile for different classes of engine plants, with the number of roads from which the averages have been calculated.

While the ton-mile should properly be the basis, yet the difficulty of determining the number of ton-miles has led to the adoption of the car-mile as the best practical unit of comparison.

Table No. 12 shows a saving of 36% between the high-speed engine plant running non-condensing at 36 lbs. of steam, and the Corliss compound-condensing at 23 lbs. Table No. 15 shows that the high-speed engine plant averages about 15 lbs. of coal per car-mile, while the Corliss compound-condensing averages about 8 lbs.—a saving of 46%, sufficiently close to the 36% given above to indicate that the coal tables give fairly accurate averages. By examining the coal tables we

are led to the conclusion that the efficiency of each system is approx- Mr. Davis.
imately the same, for we find, in general, that, where the number of car-miles is high, the consumption of coal per car-mile is low. In the North Central and Western States, where coal is not of as good quality as in the Eastern States, the consumption is higher (assuming, as we safely can, for our purpose, that the economy of various types of boilers is practically the same); with roads using hard coal there is an apparent higher average in consumption of coal, no doubt due to lower car-mileage and fewer cases; and as more economical apparatus is used in engine plants, the coal consumption decreases. It would seem, therefore, that we are correct in assuming that the total efficiency of each system is approximately the same, though varying in each part that goes to make up the whole. The variation from 25.9 maximum to 5 lbs. minimum shows the average approximate value of this information.

The amount of coal consumed per car-mile is dependent upon so many conditions, often unknown, that this amount, in any given case, cannot be used to predict what the consumption will be on another road; hence the importance of taking a large number of cases upon which to base average results, which may then be considered fairly reliable for the determination of possible results in any new case. It will readily be seen that the amount of coal consumed per car-mile depends upon the tons moved, the height through which each ton is moved, the speed, and the efficiency of the entire system. The first three are almost impossible to obtain on any large number of roads from the ordinary records kept, and can usually be secured only by specially arranged tests. The efficiency of the system depends upon that of each part, such as the boiler plant, engines, condensers and piping, generators, overhead line, ground-return, track, and equipment. High economy in all but one part of the system might cause the pounds of coal per car-mile to be high, and it is therefore impossible, without special test, to determine accurately the cause of low efficiency in any given case. By taking a large number of cases, and eliminating those which are evidently far from the average, we get approximate information indicative of what we may expect.

From Tables Nos. 13, 14 and 15 the average coal consumption per car-mile, under the best conditions of electric street-railway practice, is found to be about 8 lbs. The average weight of these cars, loaded, cannot exceed 8 to 10 tons, so that a six-car train would consume 48 lbs. per train-mile for a maximum weight of 60 tons and average speed certainly not exceeding 10 miles per hour; while with a steam train the consumption would be 58.8 lbs. per train-mile for a maximum weight of 200 tons and average speed of 20 miles per hour. If we compare with compound locomotives, Fig. 10 is of considerable interest. It indicates even a greater saving than 20% which increases as

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TABLE No. 13.

Steam Plant.					Coal.			
Road.	State.	Car-miles.	Boilers.	Engines.	Kind.	Coal field.	Tons used. (2 240 lbs.)	Pounds used per car-mile
North Atlantic States (As per U. S. Census—1890).								
56 *E*	Maine	116 926	V. T.	V.C.	S.	Virginia	508	9.7
42 *E*	Massachusetts.	196 824	R. T.	C.C.C.	S.	Georges Creek, Md.	939	10.7
65 *E*	"	16 794 961	.....	.....	S.	.....	52 878	7.0
189 *E*	"	917 956	W. T.	H.S.C.C.	S.	Georges Creek, Md.	2 201	5.4
74 *E*	"	873 177	.....	.....	S.	.....	2 262	5.8
451 *E*	"	226 123	R. T.	C.C.	S.	.....	504	5.0
308 *E*	Ohio	1 378 518	.....	.....	S.	Pennsylvania	3 189	5.2
802 *E*	Connecticut	146 000	V. T. / R. T.	H.S.C.	S.	.....	1 000	15.3
398 *E*	New York	819 000	V. T.	V.C.C	S.	Pittsburg	2 176	5.9
78 *E*	"	2 162 134	W. T.	V.C.	H.	.....	8 758	9.1
249 *E*	"	637 290	W. T.	H.S.C.C. / C.C.C.	S.	.....	5 100	17.9
214 *E*	"	199 290	W. T.	.....	S.	.....	1 460	16.4
281 *E*	"	350 000	W. T.	H.S.	S.	Reynoldsville, Pa.	1 200	7.7
181 *E*	"	295 325	R. T.	V.C.C.	S.	Clearfield, Pa.	682	5.2
80 *E*	"	7 164 258	W. T.	V.C.C.	S.	Reynoldsville, Pa.	23 597	7.4
724 *E*	"	137 970	V. T.	H.S.	H.	.....	1 460	23.7
609 *E*	"	4 558 136	.....	.....	S.	.....	19 043	9.3
842 *E*	"	73 377	R. T.	H.S.C.C.	S.	.....	640	19.5
608 *E*	"	247 482	.....	.....	S.	.....	1 139	10.2
90 *E*	New Jersey	87 923	R. T.	H.S.	S.	Clearfield, Pa.	387	9.8
558 *E*	Pennsylvania	149 730	R. T.	H.S.	S.	.....	1 231	18.4
229 *E*	"	600 000	V. T.	V.C.	H.	Hazleton, Pa.	3 600	13.4
211 *E*	"	514 989	R. T.	C.	H.	Girardville, Pa.	2 852	12.4
54 *E*	"	400 648	W. T.	H.S.C.	S.	Dawson, Pa.	1 697	9.4
580 *E*	"	501 400	W. T.	H.S.	H.	Schuylkill Co., Pa.	2 250	10.0
103 *E*	"	833 000	R. T.	C.C.	H.	Liken's Valley, Pa.	3 000	8.1
North Central States (As per U. S. Census—1890).								
648 *E*	Missouri	2 021 938	V. T.	C.	S.	Illinois	16 670	18.5
150 *E*	Ohio	449 680	.....	C.	S.	Jackson Co., Ohio	2 555	12.7
576 *E*	"	331 000	R. T.	H.S.	S.	Wellston, Ohio	1 500	10.1
220 *E*	"	363 040	R. T.	C.	S.	" "	2 300	14.2
222 *E*	Indiana	319 345	V. T.	C.	S.	Illinois and Indiana	3 140	22.0
107 *E*	Illinois	1 514 892	W. T.	C.C.	S.	.. .. ..	9 080	13.3
43 *E*	"	530 000	W. T.	H.S.C. / H.S.C.C.	S.	Streator, Ill.	4 400	18.6
256 *E*	"	425 000	R. T.	C.	S.	" "	3 500	18.4
250 *E*	Wisconsin	150 000	R. T.	H.S.	S.	Duquoin, Ill.	1 500	22.4
594 *E*	"	515 000	W. T.	V.C.C. / H.S.C.C. / C.	S.	Pittsburg, Pa.	2 190	9.5
170 *E*	Minnesota	1 133 188	W. T.	C.C.C.	S.	.....	5 510	10.9
148 *E*	Iowa	1 549 060	V.W. T.	H.S.C.	S.	Violo, Ill.	11 400	16.5
257 *E*	Missouri	223 130	R. T.	H.S.	S.	Pittsburg, Kan.	2 090	21.0
648 *E*	"	2 021 938	.....	.....	S.	.....	16 670	18.5
825 *E*	"	395 650	R. T.	C.	S.	Crawford Co., Kan.	2 150	12.2
743 *E*	"	378 995	R. T.	C.	S.	Pittsburg, Kan.	1 980	11.7
53 *E*	Nebraska	100 000	R. T.	H.S.	S.	Kansas	800	17.9
295 *E*	"	1 145 158	V. T. / R. T.	H.S. / H.S.C.	S.	Iowa and Missouri	9 802	19.2

TABLE No. 13—(*Concluded*). Mr. Davis.

Road.	State.	Car-miles.	Steam Plant. Boilers.	Steam Plant. Engines.	Coal. Kind.	Coal. Coal field.	Coal. Tons used. (2 240 lbs.)	Coal. Pounds used per car-mile.
South Atlantic States (As per U. S. Census—1890).								
811 *E*	D. of Columbia	534 000	V. T.	H.S.	S.	Cumberland, Md....	1 800	7.5
809 *E*	"	365 000	R. T.	C.	S.	"	1 500	9.2
813 *E*	"	528 500	W. T.	H. S. H. S. C.	S.	W. Virginia.....	2 080	8.6
128 *E*	Georgia.....	98 550	W. T.	H.S.	S.	Alabama	638	14.5
Western States (As per U. S. Census—1890).								
157 *E*	Colorado.....	3 451 136	R. T.	C. H.S.	H.	Trinidad, Colo.....	25 000	16.2
901 *E*	"	138 375	R. T.	H.S.	S.	Colorado.....	1 350	21.8
463 *E*	Utah.....	201 890	R. T.	C.C. H.S.C.	S.	Rock Spring, Wyo., Pleasant Valley, U'h	838	9.3
660 *E*	"	658 416	R. T.	H.S.	S.	Rock Spring, Wyo., Pleasant Valley, U'h	3 328	11.3
704 *E*	Washington..	157 832	.....	.....	S.	.....	1 825	25.9
457 *E*	California....	923 694	R. T.	C.C.	S.	.....	2 436	5.9
751 *E*	"	424 529	R. T.	H.S.C.C.	S.	.....	1 250	6.6
Canada.								
796 *E*	Br. Columbia	381 400	R. T.	C.C.C.	S.	British Columbia.....	1 200	7.0
777 *E*	Ontario.....	6 212 045	W. T. R. T.	C.C.C. H.S.C.C.	S.	.....	18 535	6.7
364 *E*	Quebec	4 888 486	F.	C.C.C.	S.	Cape Breton, N. B....	16 456	7.5

See note under Table No. 15, for explanation of abbreviations.

the speed rises. Average practice gives about 5.5 lbs. of coal per I. H.-P. per hour in single-cylinder steam locomotives, but the character of the service makes it likely to have enormous variations, in any given run. At times this figure is very much exceeded, and also often falls, under favorable conditions, to 4.5 lbs. The conditions which produce such large fluctuations in steam-locomotive service do not exist in the central power station of an electric road. In the latter case we cannot safely figure on less than about 2½ lbs. of coal per I. H.-P. per hour. This may be reduced in exceptional cases, but will more often be exceeded. Apparently, this is a decided saving in favor of the electric road, but it is only apparent. Let us assume the following efficiencies, which are fair averages: Engine, 90%; dynamos, 90%; line, 80%; and railway motors, 75 per cent. In considering these figures it must be remembered that most of the time the larger part of

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TABLE No. 14.—AVERAGES. NUMBER OF ROADS AND AVERAGE POUNDS PER CAR-MILE.

Locality.	Number.	POUNDS PER CAR-MILE.		
		Highest.	Lowest.	Average.
ALL ROADS.				
North Atlantic States	26	23.7	5.0	10.65
South " "	4	14.5	7.5	9.95
North Central "	18	22.4	9.5	15.97
Western "	7	25.9	5.9	13.86
Canada	3	7.5	6.7	7.20
Totals and averages	58	....	....	12.46
ROADS USING SOFT COAL.				
North Atlantic States	20	19.5	5.0	10.01
South " "	4	14.5	7.5	9.95
North Central "	18	22.4	9.5	15.97
Western "	6	25.9	5.9	13.46
Canada	3	7.5	6.7	7.20
Totals and averages	51	....	....	10.38
ROADS USING HARD COAL.				
North Atlantic States	6	23.7	8.1	12.78
South " "	..	....	...	.....
North Central "	..	....	...	.....
Western "	1	....	...	16.20
Canada	..	....	...	.....
Totals and averages	7	....	....	13.27

See note under Table No. 15, for explanation of abbreviations.

TABLE No. 15.—AVERAGES (AS PER GROUPING OF ENGINES).

Engine Plant.	No. of Roads.	POUNDS PER CAR-MILE.		
		Highest.	Lowest.	Average.
C	9	22.0	9.0	14.5
C. C.	7	13.4	5.0	9.2
C. C. C.	7	10.9	5.2	8.0
H. S.	13	23.7	7.5	15.0
H. S. C.	3	16.5	9.4	13.7
H. S. C. C.	3	19.5	5.4	10.5

NOTE.—The following abbreviations are used in Tables Nos. 13, 14 and 15.

F. = Flue.
V. T. = Vertical tubular.
R. T. = Return "
W. T. = Water tube.
V. W. T. = Vertical water tube.
C. = Corliss.
C. C. = " condensing.
C. C. C. = Corliss compound-condensing.
H. S. = High-speed.
H. S. C. = " condensing.
H. S. C. C. = " comp'd-condensing.
S. = Soft coal.
H. = Hard "

the system is running considerably below its rated maximum point of economy; some engineers might place motors at 80%, making the combined efficiency of the entire system about 48.6 per cent. It therefore appears that, for a given average horse-power required at the driving-wheel to move trains, double that amount, or, for safety, even more, must be placed in the central power station, making the coal consumption 5.1 lbs. per I. H.-P. per hour at the motor car, which is but little better than the average of single-expansion steam-locomotive practice, while if compared with compound locomotives (4.4 lbs.) it is higher. It must be remembered, however, that we have been comparing the best electric railway results at low speeds and light weights with average practice in steam locomotives at high speeds and heavy weights; and, while the efficiency of present electric railways is probably less than if they were operated under railroad conditions, it is improbable that this advantage would compensate entirely for the higher speeds and weights which would be moved under such circumstances. Mr. Davis.

STEAM CONSUMPTION OF BALDWIN LOCOMOTIVES AT VARIOUS SPEEDS.

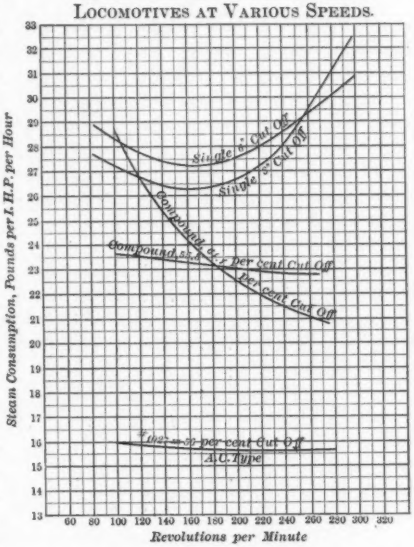

FIG. 10.*

It is interesting to note, as bearing on this subject and as additional indication of the correctness of our position, that a steam road, from which the writer has data, using over 200 000 tons of coal per annum and operating over 42 000 000 car-miles, consumes about 11 lbs. of coal per car-mile in its locomotives. Remembering that the weight moved, in this case, is considerably more than double per car (exclusive of other conditions), and that small detached steam plants are used, running high pressure and single expansion, this is strong corroborative evidence. Turning to Table No. 16 we find that the cost per train-mile on the railroads of the New England States is about 95 cents, or 19 cents per car-mile; this includes freight trains, which, if

* The diagram, Fig. 10, is taken from a paper by Mr. S. M. Vauclain, before the St. Louis Railroad Club, November 11th, 1898.

TABLE No. 16—(*Continued*).

—	23	Average distance traveled per passenger (miles)	17	.....	.....	.....	.....	....
+	24	Number of passengers carried one mile (passenger-miles or movement)	1 853 911 708	.....	.....	.....	.....	....
+	25	Number of passengers carried per square mile of settled area	1 892	7 500	3.96	.....	.....	....
+	26	Passenger trips per capita per annum in New England	23	92	3.96	.....	.....	....
+	27	Passenger trips per capita per annum of urban population in towns 8 000 and upward (89 towns)	44	174	3.96	.....	.....	....
+	28	Passenger trips per capita per annum of urban population in towns 2 500 and upward (248 towns)	31	123	3.96	.....	.....	....
+	29	Passenger trips per capita per annum of urban population in towns 1 000 and upward (819 towns)	25	102	3.96	.....	.....	....
+	30	Passenger trips per capita per annum of population served by electric railways, Tables Nos. 28 and 29	.....	.....	.....	43	78	0.55
+	31	Passenger trips per capita per annum of population served by electric railways, Tables Nos. 28 plus 29	.....	.....	.....	74		....
+	32	Passenger earnings per capita per annum in New England ($)	7.32	4.64	0.63	.....	.....	....
+	33	Passenger earnings per capita per annum of urban population in towns 8 000 and upward ($)	13.88	8.78	0.63	.....	.....	....
+	34	Passenger earnings per capita per annum of urban population in towns 2 500 and upward ($)	9.78	6.20	0.63	.....	.....	....
+	35	Passenger earnings per capita per annum of urban population in towns 1 000 and upward ($)	8.11	5.14	0.63	.....	.....	....
+	36	Passenger earnings per capita per annum of population served by electric railways, Tables Nos. 28 and 29 ($)	.....	.....	.....	2.21	3.86	0.57
+	37	Passenger earnings per capita per annum of population served by electric railways, Tables Nos. 28 plus 29 ($)	.....	.....	.....	3.72		....

(*a*) Reports of 1898 are not at hand at this writing, but for the discussion this is not essential, the relative difference being of greater interest than the actual.

(*b*) This number includes all roads making separate reports to the Railroad Commissioners; many of them are owned or leased to one of the large systems operating in the New England States, but for comparison the above figure is correct.

(*c*) While the average number of cars per train for the New England States is not at hand at this time, the Pennsylvania Railroad, from 1874 to 1884, averaged 5.21 cars per passenger train; since that date the number per train has certainly increased.

(*d*) 5 cars per train.

(*e*) Freight and passengers.

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TABLE No. 16.—Comparative Statistics of Steam Railroads and Electric Railways.

New England States—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut.

Characteristic signs.	Item number.	Item.	All Steam Railroads. Poor's Manual.	All Street Railways. R. R. Reports and the Writer.	Ratio.	Street Railways in Tables Nos. 3 and 4.		Ratio.
			1897(a)	1898.	Street railway returns to steam railroad returns.	Table No. 3. (See Table No. 28.)	Table No. 4. (See Table No. 29.)	Table No. 3 to Table No. 4.
—	1	Number of roads	145(b)	172	1.18	62	34	1.82
+	2	Total passengers carried per annum	109 064 367	432 467 674	3.96	111 839 855	92 965 277	1.23
+	3	Total length of single track operated	7 602	2 393.89	0.32	1 106.45	631.39	1.75
+	4	Percentage of operating expenses to gross earnings	74.77%	67.00%	0.89	65.00	69.00	0.94
+	5	Total passengers carried per mile single track operated	14 347	182 726	12.73	101 079	147 237	0.68
+	6	Total car-miles operated per annum	157 429 890(c)(d)	83 505 207	0.53	27 682 963	22 457 371	1.23
+	7	Total passenger-train-miles operated per annum	31 485 978	83 505 207 +	2.65	.....	.....	....
+	8	Passenger earnings per mile of single track operated ($)	4'527	9 186	2.03	5 201	7 213	0.72
+	9	Passenger earnings per car-mile operated (cents)	21.86(d)	23.60	1.08	20.79	20.28	1.02
—	10	Passenger earnings per passenger-train-mile operated (cents)	109.29	23.60+	0.21	.....	.....	....
—	11	Passenger earnings per passenger per trip (cents)	31.55	5.04	0.16	5.14	4.89	1.05
+	12	Total passenger earnings per annum ($)	34 410 597	21 740 618 +	0.63	5 755 217	4 554 674	1.26
+	13	Number of passengers carried per car-mile operated	0.692(d)	4.68	6.77	4.04	4.13	0.97
—	14	Number of passengers carried per passenger-train-mile operated	3.46	4.68+	1.35	.....	.....	....
—	15	Percentage of dividends paid	4.96%	.....	.....	.....	.....	....
—	16	Percentage of interest paid	4.56%	.....	.....	.....	.....	....
+	17	Permanent investment per mile of single track operated ($)	.....	42 717	.....	32 738	42 579	0.76
+	18	Capital stock and debts per mile of single track operated ($)	.....	46 453	.....	32 855	42 031	0.78
—	19	Total operating expenses per car-mile operated (cents)	19.00(d)	16.52	0.87	13.20	14.11	0.93
—	20	Total operating expenses per passenger-train-mile operated (cents)	95.00(e)	16.52+	0.17	.....	.....	....
—	21	Passenger earnings per passenger per mile (cents)	1.86	.....	.....	.....	.....	...
—	22	Number of passenger-miles per passenger-train-mile	58.88	.....	.....	.....	.....	

Mr. Davis. eliminated, would reduce the cost per train-mile and car-mile for passenger trains. Electric railways in the New England States operate at an average of 16.52 cents per car-mile. We also see from Table No. 11 that the average cost of fuel for locomotives is 8% of the total cost per car-mile (passenger and freight), while, for central power stations, it is 5.4 per cent. Combining these figures and allowing for the use of compound locomotives (but making no deduction for freight trains) we have 1.29 cents per car-mile for locomotive fuel and 0.89 cent per car-mile for central power stations. The difference of 31%, apparently in favor of the electric system, in the light of the foregoing data, is due undoubtedly to light weights, low speeds and including freight trains (say 30 cars per train) in the steam-railroad estimate of cost per car-mile, and which would certainly disappear under steam-railroad conditions.

The cost of coal would depend largely upon the amount of power necessary to operate a given road; for the larger the power and more frequent the trains the greater the saving by the use of electric traction. Many central stations, assumed to produce a horse-power at lower cost than by smaller units, really do not, mostly due to the fact that so large a part of such a station is idle many hours of the day; and, although at their maximum point of economy they are far ahead of small units, the question at issue is not "the cost of a horse-power at the station," but "the cost of a horse-power at the rim of the driving wheels." The cost of this last-mentioned horse-power for electric traction is not only made up of station expenses, but also line expenses and electrical equipment expenses, when compared with the cost of the same horse-power produced by a steam locomotive. When these facts are taken into consideration it is invariably found that the controlling factor is the headway of trains; the less the headway, the more chance for electric traction to pay, and *vice versa*, so far as the cost of a horse-power at the rim of the driving wheel is concerned, as affected by the amount of fuel burned. The figures given show this clearly.

The cost of handling coal would be substantially the same with either system, as there would be only one coaling station in either case. The cost of water would undoubtedly be greater in steam-locomotive practice, where it must be supplied at various points along an extended line; but on short suburban roads, to which our discussion is limited, the steam locomotive could make a round trip without requiring water, or would have to be supplied only at each end of the line; and, as the central power station would use much more water on account of larger horse-power and the use of condensing, it is hardly likely that there would be any great difference between the systems. The use of oil and waste on the motor cars should be much less than that which is necessary for the proper care of steam locomotives;

TABLE No. 17.

Case 1, Fig. 11.

(*a*) Unlimited amount of water power.

(*b*) Two sources of power, each 100 miles from the line of railway (85 miles long) and dividing the same into ¼, ½ and ¼.

(*c*) Development of these water-powers to cost no more than eleven power stations in Case 2 (this is highly unlikely, but favors Case 1 as against Case 2).

(*d*) Three-phase alternating current of 20 000 volts to be used from source of power to sub-stations, and 1 000 volts direct current from sub-stations to railway motors (this favors Case 1 as against Case 2).

(*e*) Sections, 8.5 miles long (44 892 ft.).

(*f*) Sub-sections, 11 223 ft. long, 30 in all, each with a sub-station rotary-transformer plant.

(*g*) Three tracks, minimum headway on each, three minutes; trains of five cars each, being 8.5 miles apart.

(*h*) Each train will require not more than 10 000 I. H.-P. at the stations, under economical conditions.

(*i*) Each sub-station an economical rating of 20 000 I. H.-P.

(*j*) In either case, feeder lines along the line of railway equal each other (this also favors Case 1 as against Case 2).

(*k*) All other conditions to be the same as assumed in a previous article by the writer.*

Case 2, Fig. 12.

(*a*) Eleven power stations, one for each section and one at each end of the line, 8.5 miles apart, each supplying current to 3 sub-stations with rotary transformers—sub-stations 2.125 miles apart.

(*b*) Cost of the eleven power stations, each 30 000 I. H.-P., economical rating to equal the cost of developing water powers in Case 1 (favoring Case 1 as against Case 2).

(*c*) Three-phase alternating current of 10 000 volts from power stations to sub-stations, and 1 000 volts direct current from sub-stations to railway motors (this favors Case 1 as against Case 2).

(*d*) All other conditions similar to *e*, *f*, *g*, *h*, *i*, *j* and *k*, of Case 1.

* "The Enormous Possibilities of Rapid Electric Travel." *Engineering Magazine*, 1897.

electric motors can have their wearing parts run in oil boxes, which are a protection against dust and dirt, and automatically lubricate the surfaces subjected to friction, but this cannot be done in the case of steam locomotives. This saving in an electric system is, however, counterbalanced by the use of oil and waste in the central power station, so that it is unlikely that there would be much, if any, difference. The figures in Table No. 11 indicate, however, that there is a saving of about 50% in each of these items as compared with steam railroad results.

Thus far we have considered an electric line with power stations located adjacent to the track and with the usual 500-volt direct-current system. If a cheap source of power (waterfall), located at a distance, with the power transmitted to the line, will reduce operating expenses below what they would be by the assumed method, then this saving can be compared to the results of a steam railroad; but, should the reverse be true, the latter comparison is unnecessary. An example will best bring out the facts, and, while the case is hypothetical, a

Mr. Davis. careful examination of the figures will satisfy one that the conclusion is correct, whether or not the estimates in themselves are considered accurate.

Fig. 11 shows the layout of a railroad and feeder lines utilizing a cheap source of power (Case 1), while Fig. 12 shows one for which power is generated by steam plants along the line of the road (Case 2).

Assume the conditions shown in Table No. 17.

From Figs. 11 and 12 it will be seen that the track, third rail, direct-current feeders, sub-stations, etc., will be the same in both

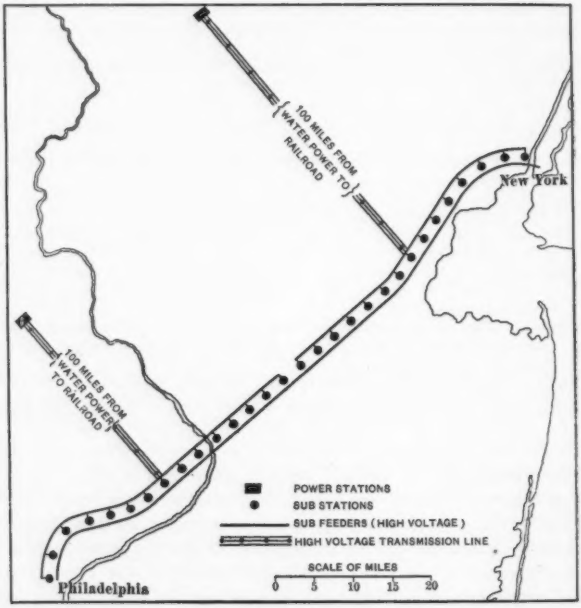

FIG. 11.

cases. The amount of copper in the high-voltage sub-feeders in Fig. 11, which run from the points where the transmission lines strike the road to the sub-stations either way, would be greater than that in the high-voltage lines from the power stations to the sub-stations in Fig. 12. The main point to consider, however, is the high-voltage transmission lines themselves (Fig. 11) from the water-powers to the points where they strike the line of the railroad. Under the above conditions, if the interest on the additional investment for these transmission lines from the "cheap source" of power to the railroad line in Case 1, exceeds the difference between Case 2 and Case 1 in cost of power delivered to

the sub-station supply feeders, then it is unprofitable to utilize the "cheap source" of power. Mr. Davis.

Our calculations, therefore, can be confined to the cost of the two transmission lines in Case 1, each 100 miles long, from the two sources of water-power to the line of railroad; and the difference in the cost of producing power at these waterfalls and the sub-station supply feeders. If the interest on the former exceeds the difference in the latter, then it is unprofitable to use the "cheap source" of power.

In making the calculations, every care has been taken to be fair to the distant source of power, and wherever then is any room for doubt, the "cheap source" has been given the benefit.

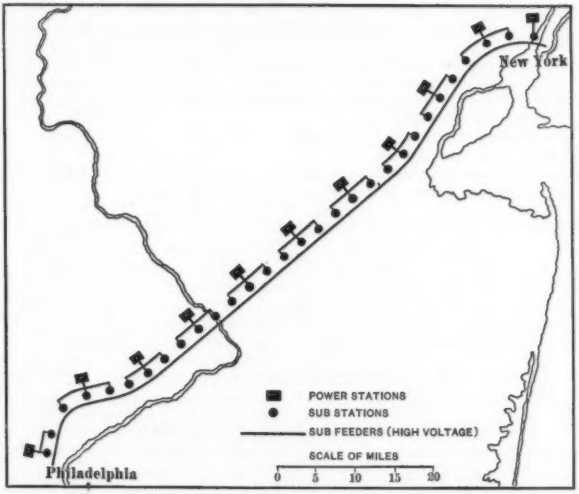

FIG. 12.

The calculation of the pounds of copper necessary is as follows:

$$\frac{\text{Circular mils}}{\text{(Diameter of wires squared)}} = \frac{\text{Current} \times \text{Distance in feet} \times 20}{\text{Volts lost in line.}}$$

$$\text{Current} = \frac{\text{Watts}}{V} = \frac{\text{Horse-Power} \times 746}{\text{Voltage of transmission.}}$$

$$\text{Pounds of copper} = 0.016 \times \text{circular mils} \times \text{miles.}$$

Therefore,

$$\text{Pounds of copper} = 1\,262\,000\,\frac{\text{Horse-Power} \times \text{miles}^2}{(\text{Voltage of transmission}) \times (\text{Loss in volts}).}$$

For 100 miles transmission at 20 000 volts, and a loss of voltage in the line of 20%, or 4 000 volts the formula becomes:

$$\text{Pounds of copper} = 158 \times \text{Horse-Power.}$$

Mr. Davis. This is correct for direct current. For alternating, the inductive loss would increase the amount of copper required to obtain the same total percentage loss, or, if the same amount of copper were used, would increase the total percentage loss. At the same time there would be a saving due to the three-phase wiring system, which would partly counterbalance the loss due to induction. The actual formula would have to be deduced for each special case of wiring, but, on the whole, the above formula, used directly, is sufficient for our purpose.*

As the horse-power to be transmitted equals 412 500 at 20% loss (330 000 H.-P. delivered at the railroad line), the total amount of copper necessary is 65 175 000 lbs.

We therefore make the comparison shown in Table No. 18.

TABLE No. 18.

	Case 1.	Case 2.
Allowable loss in pressure from water-powers to railway line	20%	.....
Total horse-power to be delivered to railway line at supply feeders of sub-stations	330 000	330 000
Total horse-power at source of power	412 500	330 000
Number of power stations	2	11
Total horse-power at each power station	206 250	30 000
Total distance power is transmitted from each station (miles)	100	0
Pressure at source of power (volts)	20 000	10 000
" " railway line (volts)	16 000	10 000
" lost in line (volts)	4 000	0
Number of sub-stations supplied from each source	15	3
Average length of sub-feeders (miles)	10.625	4.25
Number of sub-stations on each group of sub-feeders	7.5	3
Pounds of copper in transmission line	65 175 000	0

To the total cost of transmission line, amounting to $25 000 000 (in round numbers), should be added the additional cost of developing the two water-powers to 412 500 H.-P. as against 330 000 H.-P. in the eleven steam-power stations along the railroad line. There should also be added the additional cost of feeder lines from the two railroad terminals of the transmission lines to the sub-stations, as against the cost of feeders from the steam-power stations to the sub-stations. While these two items would undoubtedly amount to several million dollars in the case under discussion, we have omitted them, owing to the difficulty of estimating the former without accurate surveys of special localities to be developed; their omission favors Case 1. So far, we have an excess in first cost of $25 000 000 against Case 1 as compared with Case 2.

---

*The correct formula is: Circular mils $= \frac{D \times W}{P \times E^2} \times K$;

where D = distance one way in feet,
W = total watts delivered to consumer,
P = percentage of loss in line of W,
K = 1 600,
and E = potential between conductors at consumers' end of line.

Table No. 19 is an estimate of the cost of our proposed transmission line. Mr. Davis

TABLE No. 19.

Right-of-way—two strips 100 ft. wide and 100 miles long = about 2 500 acres at $1 000 average	$2 500 000
Engineering, 2% on $15 000 000	300 000
Clearing 600 acres at $100	60 000
Bridges, viaducts, or submarine cables, say (an approximate estimate).	1 500 000
Fencing	200 000
Crossings, say 120 at $1 000	120 000
Signals for guarding and repairing 200 miles at $1 000	200 000
Telegraph, 200 miles at $1 000	200 000
Narrow-gauge repair track and equipment, 200 miles at $5 000	1 000 000
Feeders, 65 175 000 lbs. at 15 cents in place	9 780 000
Pole line, 11 000 poles set in concrete at $100 each	1 100 000
Discount on $25 000 000, 3% 100-year bonds	1 250 000
Interest on bonds to opening of road, say 10 years of construction, averaging $2 500 000 per annum at 3%	4 125 000
Taxes to opening of road, assuming ¼ assessment and 2% rate	1 375 000
Office expenses, salaries, etc., to opening of road, 2% on $15 000 000	300 000
Contingent, etc., not itemized, to opening of road, 5.2%	1 300 000
Total cost	$25 310 000

Table No. 20 is a comparison of the running expenses under the two conditions, based upon the calculations in "The Enormous Possibilities of Rapid Electric Travel," already referred to, the items being given in percentages of the total cost per car-mile run, and being reasonable averages (Table No. 11, Column 8).

TABLE No. 20.*

	Case 1.	Case 2.
Repairs of N. G. track on transmission line right-of-way	1.0%	.....
Repairs of fences, crossings, etc., on transmission line right-of-way	0.1%	.....
Repairs of feeder lines on transmission line right-of-way	6.0%	.....
Renewals of poles and insulation on transmission line right-of-way	1.5%	.....
Renewals of feeder on transmission line right-of-way	1.0%	.....
Repairs of bridges and trestles on transmission line right-of-way	0.3%	.....
Repairs of buildings on transmission line right-of-way	0.1%	.....
Repairs of signals and telegraph on transmission line right-of-way	0.5%	.....
Fuel for power stations	.....	8.0%
Water supply	.....	1.0%
Oil and waste	0.5%	1.0%
Repairs of power stations	2.0%	4.0%
Power station wages	2.0%	4.0%
Average horse-power developed at source of power	412 500	330 000
Total car-miles per annum	43 435 000	43 435 000
Total cost per car-mile	.....	15 cts.
Add for excess power developed by water-powers (25%) say	3.0%	.....

* All other items being the same, the reader is referred to the other articles mentioned in this discussion.

Mr. Davis.

From Table No. 20, it is seen that the items added to the cost per car-mile by the use of water-powers located 100 miles away about balance the greater cost of fuel, water, oil and waste, repairs to power stations, and power-station wages, where the stations are located close to the tracks and operated by steam power (each amounts to 18 per cent.). Hence the total expenses would be practically the same for each case. As the transmission lines cost $25 000 000, the interest thereon is the total increase in the expense of utilizing the water-powers instead of steam-power plants. This interest may be figured at 3% ($750 000), 4% ($1 000 000), 5% ($1 250 000), 6% ($1 500 000), or even 10% ($2 500 000), as the case may require, or good judgment dictate. The use, therefore, of these supposed water-powers would decrease the earning capacity instead of increasing it.

Let us, for the moment, assume that our calculations of the operating expenses with the use of water-powers is inaccurate, that in many of the items there is a greater saving, and that those having no counterpart in the other column can be materially reduced.

TABLE No. 21.

Interest.	Car-miles.	Total Interest.	Saving in Cents per Car-mile which must take place to allow the investment.
10%	43 435 000	$2 500 000	5.81
6%	"	1 500 000	3.68
5%	"	1 250 000	2.90
4%	"	1 000 000	2.32
3%	"	750 000	1.74

But 18% (total of percentage items in Table No. 20) of 15 cents (assumed cost per car-mile) equals 2.7 cents; so that, at the five interest rates, we can afford to have our figures wrong by the percentages shown in Table No. 22.

TABLE No. 22.

With interest at 10% — 266% of 18% = (38% of total)
" " " 6% — 133% " " = (24% " ")
" " " 5% — 105% " " = (19% " ")
" " " 4% — 83% " " = (15% " ")
" " " 3% — 64% " " = (11% " ")

It is unlikely that we have made any such error as would be necessary to show that, even with money worth only 3%, it would pay to utilize the water-powers in the case we have discussed. Furthermore, we have favored Case 1 in every way, and more especially by comparing a 20 000-volt system with one of 10 000 volts.

Had we used higher voltages on our transmission line, the copper would have cost:

At 50 000 volts	63 × H.-P. = 10 310 000 lbs.	$1 555 000.
" 100 000 "	25 × H.-P. = 2 600 000 "	390 000.

Mr. Davis.

By using higher voltages some items of the first cost would be slightly reduced, but, as these constitute more than 60% of the total cost, whereas copper constitutes less than 40%, a reduction in the latter increases the percentage of the former, although reducing the actual amount. Using 100 000 volts, the first cost would not be less than $10 000 000; the interest on this at 3% equals $300 000, and the corresponding saving per car-mile which must take place to allow this investment equals 0.7 cent; therefore 25% of 18% (4.6% of total) can be allowed, even in this case, for errors in our calculation.

The case we have discussed shows conclusively that it would not pay to utilize the water-powers. But, it may be said, this covers only one problem. While this is true, nevertheless this problem is one chosen to enable us to arrive at a general conclusion; for we are dealing with a very large amount of power at a comparatively short distance. The larger the power to be used, the more likely it is that a cheap source will prove profitable; the greater the distance over which the power must be transmitted, the less likely it is that a cheap source will prove profitable.

These calculations have been given to bring out clearly how unlikely it is that, even by the use of alternating long-distance transmission, a trunk line like the Pennsylvania Railroad, for example, will convert its entire system to electric traction. This system, east of Pittsburg, has 2 747.35 miles of railroad, 8 259.36 miles of single track, 1 803 locomotives, 1 765 passenger, baggage and express cars, and 90 527 goods cars. If locomotives were converted at an average horse-power of 300 each, this would make an aggreate of 216 360 H.-P. to be transmitted (allowing 20% in shops and 50% of the total horse-power of the locomotives to be transmitted), while it would have to be taken over many times the distance given in the example. Apply the formula for pounds of copper in transmission line and we see how enormously the weight is increased as the distance increases in the case of the Pennsylvania Railroad. The cost is astonishing when one remembers the claims of an enthusiast who stated: "Where water-power is always available within a few hundred miles" or "for desert railways, where water cannot be obtained," "electric traction is eminently suitable."

Repairs of passenger locomotives and tenders on steam roads average from 4 to 6 cents per mile, with about 1.5 cents to be added for repairs to tools, shops, machinery, etc., properly chargeable to "motive power repairs." Statistics of electric roads are very imperfect and unreliable on matters of this kind, not only because, in the past, such roads have usually been operated by those familiar with horse traction, and having little mechanical knowledge of or inclination toward the precise methods of steam-railroad management and operation, but because of the constant change of apparatus long before the old had given the life which could reasonably be expected of it as a piece of mechanism.

Mr. Davis.

Even if we had such data as we might wish from existing electric roads, they would be only indications of what might be expected on a system similar to the one under discussion. From Table No. 11 we find that locomotive and passenger car repairs amount to 9%, while motors, trucks and cars on the electric railroads of Massachusetts cost 9.2%, which again favors the steam railroads; for to this must be added 2% for power-plant repairs, making a total of 11.2 per cent.

When we remember the small horse-power involved, and the light weights and low speeds, it is hardly likely, with the large increase in these necessary under steam-railroad conditions, that the cost of repairs and maintenance of the motive power of an electric road will be any less than that of a steam road. It is to be regretted that more reliable and extensive data are not obtainable. Repairs and maintenance of passenger cars would be the same in either system. The item "use of foreign passenger cars" is the rental paid for the use of cars of other roads while retained, and of course would be unaffected by the use of any particular system. While the operation of a motor car involves far less labor than that of a steam locomotive and its tender, yet the danger that the operator might be incapacitated makes it necessary to have two men at the head of the train, although one man would easily be able to do all the required work. As it takes two men to run the ordinary passenger locomotive, there would be no advantage of one system over the other. It would be a mistake to save wages by utilizing a lower degree of intelligence or skill for motormen and their assistants than is now used for engineers and firemen on steam railroads; the tendency to do this has cost electric street-railway owners many thousands of dollars—more, in fact, than is usually realized. Passenger-train service would not be affected by the use of one system or the other. Central-power-station service is an additional charge against the electric road. Were the operative method changed, train services (wages) would be greatly increased, as shown in Table No. 11.

We now come to (*c*) "Station, Terminal, Taxes and General Expenses," divided into ten subdivisions, none of which is affected by the character of road-bed, rolling stock or mechanical apparatus of any kind, but is dependent upon the character of the business handled, the mode of operation and the volume of traffic; therefore these items are unaffected by the use of any particular motive power. The same statements apply to the division (*d*) "Accident, Loss and Damage," and to (*e*) "Interest Account."

"Fixed charges" includes interest on bonds, and rentals; the actual rate of interest on bonds is not affected by the system used, except in ways beyond the scope of this discussion. We have shown that the first cost of an electric system is considerably greater than that of a steam-locomotive road when operating under the same conditions, and

only in one case will it be less, namely, when the units are small, light and very frequent, when the cost of locomotives would more than equal the natural increases caused by electricity. Mr. Davis.

Therefore the "fixed charges" of an electric system, under steam-railroad conditions will be much higher, and this may vary from 5 to 15% or more as an increase of expenses against the electric road, assuming, of course, that the cost in each case is covered by bonds, which is now usual.

This is no inconsiderable item, as the average fixed charges of our present steam roads are not less than 20% of the gross receipts, and, if this is increased largely by the use of electricity, it is more of a burden than can be overcome by inconsiderable savings in items of operating expenses (if such savings are even possible), such as slightly lower coal consumption, motor car repairs and maintenance, bridge repairs and maintenance, track repairs and maintenance, etc., which may be claimed in favor of electricity by some ardent advocates, irrespective of the intrinsic merits of any given problem.

To recapitulate: We see, by Table No. 11, that the additional charges against electric traction, omitting interest on increased fixed charges, amounts to 6.97%, while the savings, allowing the maximum in each case and all doubtful items, is 4.95%; or 2.02% against the electric system, with the largest of all items not considered.

From what precedes we have shown that the following would be additional charges against the electric road over a steam railroad, and that they would not be inconsiderable, especially the interest charge:

1. Interest on increased cost.
2. Renewal and repairs of transmission line.
3. Repairs of motors and central power plants.
4. Central-power-station services.

And the following the possible, but not necessarily probable, savings:

1. Renewal of rails.
2. Repairs of bridges, trestles, etc.
3. Fuel for central-power plants (unlikely).
4. Water supply (unlikely).
5. Oil and waste (unlikely).

These are items of sufficient importance to necessitate a very careful study of each individual problem before deciding upon a change, or even an original installation.

But some may say that the average of 17 cents per car-mile is high for electric roads, and so it is for a first-class well-managed road, but so is 19 cents for a similar steam road. The Metropolitan Street Railway of New York makes the statement that they operated at 11.95

Mr. Davis. cents per car-mile, while in an article in *Cassier's Magazine* of August, 1899, the statement is made that the Chicago South Side Elevated operated, in the month of December, 1898, at 7.5 cents per car-mile. Both these figures must be taken with a great deal of caution, and for the same reason, namely, the period during which both systems have been in operation has been short, and neither yet knows what its true operating expenses are. Table No. 11 (last column) indicates this. In this table it is seen that the "train expenses" of the Metropolitan Street Railway, most items of which are unaffected by time, are approximately equal to the average of all Massachusetts roads, which have been running several years, while "maintenance and renewal of way and works" are about 25% of the Massachusetts roads. "General expenses" are also about 25%, and accidents about 70 per cent. General expenses were distributed between cable, horse and electric systems; but, assume that these figures are correct, and that an electric road can be operated at 7.5 cents per car-mile, even then they are not approaching the best steam railroad results. The Pennsylvania Railroad Division of that system operated, in 1897, about 5 cars per passenger train and 30 cars per freight train (both figures are probably underestimated); a total train mileage of about 50 000 000 was made, divided into 16 000 000 passenger-train-miles and 34 000 000 freight-train-miles. The cost per train-mile was about 75 cents for the total mileage. Taking 75 cents as the actual cost per train-mile, for either passenger or freight, we would have 15 cents per car-mile as operating expenses for passenger cars and 2.5 cents per car-mile for freight. This method of estimating is obviously wrong, for a freight-train-mile must cost more than a passenger-train-mile, but the former would have to rise above the average to $2.25 per freight-train-mile before the cost per car-mile would increase beyond 7.5 cents. Again, the average weight of an electric car may be taken at 20 000 lbs. (10 tons), so that at 7.5 cents per car-mile the operating expenses would be 0.75 cent per ton-mile, while the Pennsylvania Railroad Division operated at 0.311 cent per ton-mile.

In making a comparison in the use of steam locomotives and electric motors as motive powers, it is seen that only where the units are many, light and frequent, and operated over comparatively short distances, can the use of electricity result in lower first cost or operating expenses; but this involves a change in the method of operation for it to prove desirable. Where units are few, heavy and infrequent, and operated over long distances, the use of steam locomotives will result in lower first cost and operating expenses, and prove more desirable. Though this general statement may be modified by special conditions, such as very high speeds at frequent intervals, it will generally govern in determining changes, or the choice of one or the other, in the case of newly projected roads.

Without trying to define the exact limit beyond which electricity would be injudicious, we can state that, except for suburban traffic, and interurban traffic between towns a short distance apart, electric traction is to-day higher in first cost and operating expenses; and even when used under such conditions, it may still be so, and success will only come with a corresponding change in operative methods. Mr. Davis.

The fact that usually the first cost and the total expenses will be greater with electricity than with steam might lead us to discard the thought of using the former under any circumstances, were it not for the question: How will our gross receipts be affected by the use of one or the other system? If by using electric traction we can increase sufficiently the gross receipts per car-mile or train-mile, and per mile of road, we can afford to pay for the additional first cost and greater total expenses. This is the vital question and the real one at issue, although usually not so considered; but, in general, the inducement to adopt electricity instead of steam, or to discard the latter, will be the increased travel which undoubtedly comes, in a greater or less degree, to roads using electric motors.

Freight and miscellaneous receipts cannot be affected by any change of motive power, so our discussion will be confined to the effect on passenger receipts.

3. Gross Receipts.

By examining statistics of steam railroads we find that the volume of travel is influenced by such features as the following: Convenient location of stations with respect to centers of population; length of line; proximity of terminals to the centers of population; number of trains; (the four points just mentioned have an overwhelming effect on short-haul traffic); good road-bed and track neatly kept; handsome commodious stations, with first-class appointments and service; comfortable and luxurious cars; block signals; cleanliness, etc. Profit is proportional to success in obtaining that travel which enables each train to run full, for the cost of a train-mile is not affected by the number of seats taken; and it is this travel which is obtained by a line giving weight to its "location" and "appointments." In freight competition between railroads the rates are ultimately dependent upon the cost from "consignor to consignee," not from station to station, and the railroad eventually pays the additional cost of lighterage, switching, cartage, etc., and the profit thereon, whether by actual difference in rates or loss of business.

The same is true in passenger traffic, as will be seen by free omnibuses, reduction in rates, etc. If you can take the passenger up at his own door and set him down at his place of destination, you have not only suited his convenience (and thus, as we shall see, induced him to travel oftener), but have secured those receipts which otherwise

Mr. Davis.

TABLE No. 23.—POPULATION

STATES.	Population (United States Census, 1890).	Density (population per square mile).	Total area (square miles).	Area of settlement (square miles).	URBAN POPULATION (CALCULATED FROM U. S. CENSUS 1890.)			
					Towns 8 000 and upward.		Towns 2 500 to 8 000.	
					No. of towns.	Total population.	No. of towns.	Total population.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Maine	661 086	22.11	29 895	25 729	8	130 346	39	152 677
Connecticut	746 258	154.03	4 845	4 845	17	385 287	49	204 923
Massachusetts	2 238 943	278.48	040	8 040	47	1 [illegible]4 931	103	445 018
Rhode Island	345 506	318.44	1 085	1 085	10	272 571	13	55 439
New Hampshire	376 530	41.81	9 005	8 328	5	103 058	22	85 137
Vermont	332 422	36.39	9 135	9 135	2	26 350	22	90 713
Totals and averages	4 700 745	79.79	62 005	57 662	89	2 482 543	248	1 033 907

would have gone to omnibuses, hackmen, and street-car lines. This the steam railroads have failed to do, and it is clear that they cannot altogether do away with these feeders natural to their peculiar modes and conditions of traffic ; but there is little room to doubt that in many cases steam railroads can modify their present methods, for suburban traffic out of large centers of population and for interurban passenger traffic on branch lines between centers of population, by the use of electricity, paying the additional first cost and greater total expenses out of the probable (we might say certain) enormous increase in their gross receipts. This, the writer believes, can be accomplished only by a radical change in the present methods of operation, making them approach, on parts of the system, the present "leave-at-your-door" plan of our street railways, while keeping, on the rest of the system, the present methods of steam railroads with possibly some minor modifications. To accomplish this to advantage, the use of electricity will probably prove advisable, although in some instances a combination of electricity with steam might give the best results. The great increase in gross receipts and in net revenue may, and very often will, decide the question beyond any possible doubt in favor of electricity, always remembering that the adoption of electric traction means a corresponding adaptation of operative methods, and not the mere application of a special form of motive power.

Let us consider some of the figures bearing on the problem.

The Pennsylvania Railroad originally spent about $5 000 000 for its Broad Street terminal; the great St. Louis Bridge and Union Station

STATISTICS (UNITED STATES CENSUS). Mr. Davis.

URBAN POPULATION (CALCULATED FROM U. S. CENSUS, 1890).

Towns 1 000 to 2 500.		Total in Towns 1 000 and upward.		Balance of population not in towns, 1 000 and upward.	Table No. 28.		Table No. 29 (omitting *C* 13).		Table No. 28 plus 29 (omitting *C* 13).	
No. of towns.	Total population.	No. of towns.	Total population.		No. of towns.	Population served.	No. of towns.	Population served.	No. of towns.	Population served.
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
143	209 864	190	492 887	168 199	25	175 676	9	90 219	32	210 887
56	89 894	122	680 104	66 154	52	326 252	37	401 858	77	474 420
107	172 984	257	2 182 933	56 010	144	1 850 837	32	581 668	152	1 961 280
9	14 112	32	342 122	3 384	.....	.....	....	.....	.....	.....
74	105 018	101	293 213	83 317	.....	.....	7	106 673	7	106 673
93	135 831	117	252 894	79 528	.....	.....	....	.....	.....	.....
482	727 703	819	4 244 153	456 592	221	2 352 765	85	1 180 418	268	2 753 260

cost many more millions; while the Market Street terminal of the Philadelphia and Reading Railroad, the Union Station of the Boston and Maine Railroad systems, the Southern Union Station of the New York, New Haven and Hartford Railroad in Boston, and the Grand Central Station in New York are proofs of the millions of dollars spent by railroad companies to locate their terminals at or near the centers of population. These expenditures were incurred almost entirely for the sake of increasing the suburban passenger traffic, although giving a decided stimulus to through and competitive business. In the writer's opinion, our steam railroad companies can afford to double (to use a broad and inaccurate expression) these investments to accomplish what has been suggested above, reaping a handsome return from the increased gross receipts from the passenger traffic thus obtained and encouraged.

Taking the New England States as a basis for comparison—for there we shall find the shortest hauls, the most dense population, the greatest number of trains, and the most accurate statistics—we have from Poor's Manual, Railroad Commissioner's Reports and special calculations by the writer the various tables and figures hereafter discussed.

Effect of Increased Population.—Fig. 1 shows clearly the enormous growth of population and railroad mileage in the United States since 1830, when steam railroads were just coming into existence. Street railways started at about the same time, the first street car operating on the New York and Harlem Railroad tracks, Fourth Avenue, New

Mr. Davis.

TABLE No. 24.—GROWTH OF STREET RAILWAYS IN 10 YEARS, 1888 TO 1898 (*a*).

MOTIVE POWER.	NUMBER OF RAILWAYS.		MILES OF TRACK.				NUMBER OF CARS.				AVERAGE LENGTH OF RAILWAY (MILES OF TRACK).	
					Percentage to total.				Percentage to total.			
	1888.	1898.	1888.	1898.	1888.	1898.	1888.	1898.	1888.	1898.	1888.	1898.
Electric.....	21	914	86	14 782	1.4	90.2	172	41 402	0.6	87.8	4.09	16.17
Cable.....	18	20	217	486	3.6	3.0	2 777	2 920	11.1	6.2	12.06	24.30
Horse.....	566	112	5 474	683	91.4	4.2	21 736	2 860	86.6	6.0	9.67	6.09
Steam.....	35	27	216	421	3.6	2.6	(*b*)423	(*b*)404	1.7	0.8	6.17	16.59
Totals...	640	1 073	5 993	16 372	.....	.....	25 108	47 586	.....	.....	.....	.....

(*a*) From an article by Mr. William J. Clarke, entitled "Electric Railways in America from a Business Standpoint."—*Cassier's Magazine*, August, 1899.

(*b*) Includes locomotives.

This table is evidently approximate, and was undoubtedly not intended to be exact.

York City, in November, 1832. It would be curious if in the near future (70 years after) some steam railroad should again change its mode of operation so as to approach the methods of street railways. Curves Nos. 7 and 8 show the growth of urban population (according to United States Census those communities which have 8 000 or more inhabitants), while Table No. 23 shows the urban population in Massachusetts down to towns of 1 000 inhabitants.

It is unfortunate that the old horse railways have left so few records, but Fig. 2, showing the increase of mileage in Massachusetts from 1870, gives an indication, while Table No. 24 shows the growth of street railways in ten years, 1888 to 1898. The mileage of street railways (16 000) when compared with that of steam railroads (182 000) shows that the former are confined to thickly populated areas, either within their limits or connecting two or more such areas. Their methods of operation—small, frequent units—adapted itself to such distribution of inhabitants and not to the longer hauls at infrequent intervals shown by the mileage of steam railroads.

The growth of population and industries of all kinds (including transportation) react on each other, favorably or otherwise, depending upon conditions of prosperity. A system like the Pennsylvania Railroad could not have existed in 1830, even though it could have been operated at as low a cost as to-day. It had no suburban short-haul business in its early days.

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The concentration of population into "urban" districts has come through the increased transit facilities of such communities. The horse-roads first enabled a growth which made it necessary for the steam railroads to increase their local facilities, which again reacted on the population to increase it, and then came the cable road to reduce the time spent in getting in and out from the residential sections to the business centers; this, in turn, increased the radius of urban population, and again the steam railroads reached out farther from the center of population; all of which encouraged concentration of inhabitants, and the electric railway once more caused a similar cycle of events.

There is no reason to suppose that these conditions have ceased, and that this action and reaction have stopped. It is this enormous development of the country which has allowed the constant increase of investment on transportation systems, and this in turn has increased the carriage of both passengers and freight. In the growth of transit facilities and methods the "radius of action" of the roads has increased constantly, and as it increased so did the urban population and *vice versa*; but when our cities grow beyond the present "radius of action," our transit systems must take another step. Some communities have already arrived there, and the solution will undoubtedly be the equipment of our steam railroads, running out of and between those near together, with electric traction. This will enable them to change operative methods to approach present street railway practice, thus increasing gross receipts enough to offset interest on increased first cost, and reduce operating expenses per car-mile; for the increase in present investments and traffic have also tended to reduce the cost of transportation per head.

Effect of Increased Capitalization.—Fig. 2 also shows the enormous increase in mileage and investment of street railways in Massachusetts, where the density of population is high and has increased more rapidly than in any other part of the United States, as shown by Curves Nos. 5 and 6, Fig. 1. It is because of this increase, which is still going on, that constant increased investments are warranted on established transit systems. This will induce our steam railroads to handle increased traffic in urban, suburban and interurban areas by small, frequent units, operated by electric motors, and thus also stimulate and again increase a traffic which will only grow so much and then wait to be encouraged.

Curve 6, Fig. 2, shows the tendency toward increased investment per mile; the drop from 1894 to 1896 indicates a greater increase in suburban than urban mileage, costing less per mile and thus reducing the average. Fig. 3 shows how comparatively small was the percentage of increase of steam railroad mileage, but a very distinct increase is shown in investment per mile (Fig. 3 gives totals of roads in Massachusetts, but includes mileage, etc., outside the State).

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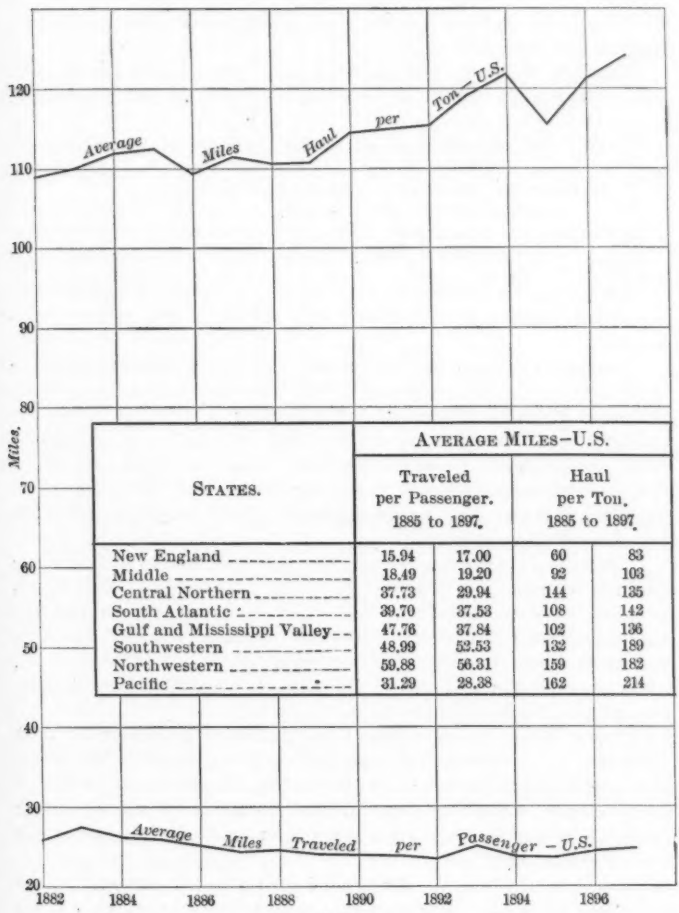
Effect of Increased Earnings.—Figs. 4 and 5 show the earnings of street and steam roads in Massachusetts. Attention is also called to Table No. 16, giving comparative statistics of steam and electric roads, and also to Table No. 10, giving the percentage of increase or decrease in all items (curves) discussed and found in the various figures, between the years 1870 and 1890. We again see the constant increase in gross receipts, especially of the street railways (400% as against 150% for freight and passengers of steam railroads, being 120% for passengers only, Fig. 7, Curve 4); and also the increase in interest and dividends on increased capitalization, some of which is not chargeable to increased mileage (also much larger for the electrics than for the steam).

The gross traffic earnings per mile increased 25% on the steam and decreased 4% on the street roads; the latter is undoubtedly due to the relatively large increase in mileage; this curve, however, has a "characteristic + sign" which will be shown in future growth in the years to come. Curves 8 and 9 in both figures show the characteristic constant reduction in receipts per car-mile or train-mile, due to increased mileage giving better facilities and thereby increasing the traffic at a slightly lower rate, both as to numbers and fares; also reduction in operating expenses per car-mile as the same increases.

Effect of Increased Traffic.—Figs. 6 and 7 (see Table No. 10 also) again bring out the same characteristic comparisons as the previous figures, and, in addition, the following: Curve 10, Fig. 7, indicates that passengers are hauled a shorter distance, on the average, every year. Fig. 13 brings this out somewhat more clearly. In the Eastern States, which are more densely populated, the average distance is approximately constant, but with a tendency to fall. In other words, the proportion of short-haul passengers to total passengers is rising as the population increases and the rides per inhabitant per annum increases.

As the long-distance telephone system develops, its use will grow to such a point that it will no doubt have a decided effect on long-distance passenger traffic, if it has not already. This will increase the proportion of short hauls as compared with long hauls, and the passenger business of our steam railroads (or their partial development into electric railways) in the future, will be more and more largely that of suburban and interurban localities. The increase in total passengers carried was 308% on the steam railroads and 507% on the street railways (see Table No. 16 for totals), while passenger-train-miles increased 204% and 364% (car-miles) respectively.

The receipts per passenger are constantly decreasing as the number of passengers increases, as shown by Curve 6 on each figure. The larger proportional increase in mileage of street railways has reversed the characteristic sign of Curve 4, Fig. 4 (receipts per mile of track), and Curve 9, Fig. 6 (number of passengers carried per mile of track),



States.	Average Miles–U.S.			
	Traveled per Passenger. 1885 to 1897.		Haul per Ton. 1885 to 1897.	
New England	15.94	17.00	60	83
Middle	18.49	19.20	92	103
Central Northern	37.73	29.94	144	135
South Atlantic	39.70	37.53	108	142
Gulf and Mississippi Valley	47.76	37.84	102	136
Southwestern	48.99	52.53	132	189
Northwestern	59.88	56.31	159	182
Pacific	31.29	28.38	162	214

FIG. 13.

Mr. Davis. when compared with Curves 8 and 9, Fig. 7, showing the same items on the steam railroads of Massachusetts. Records do not give the average miles traveled per passenger on street railways. Whether or not there is a temporary increase cannot be determined; but, that in the long run it tends to decrease, there is little room to doubt, although subject to some variation.

Table No. 25 shows the increase in passengers carried per car-mile on street railways and the decrease per train-mile on steam railroads.

TABLE No. 25.—STREET AND STEAM ROADS IN MASSACHUSETTS.

	1870.	1890.
Number of passengers carried per car-mile operated (Street Railways).....	4.91	5.51
Number of passengers carried per train-mile operated (Steam Railroads).....	4.71	4.30

This shows the increase in train-mileage of steam roads as compared with passengers carried, while the reverse is true of street railways.

Passenger rides per capita per annum and corresponding receipts per capita per annum have increased enormously on street railways when compared with steam railroads. The number of rides increases more rapidly than the receipts per capita; about twice as fast on steam railroads and 35% more on street railways, while the actual increase of the latter has been 204% and the former 100 per cent. In other words, the steam roads have been reducing fares to more nearly approach the low charges of street railways.

These results show most clearly how the low fares (total cost per trip, not per mile) and "leave-at-your-door" service of electric street railways have increased the passenger rides per annum and the number per car-mile so that low fares are profitable. In 1896, the rides per capita per annum were 116 for street railways and 44.5 for steam, while the receipts per capita per annum were $5.95 and $12.80, respectively, for Massachusetts.

Effect of Future Growth.—Figs. 8 and 9 are only indications of what the future has in store for railroads and railway systems in Massachusetts. The predictions have been plotted by taking two points on the street-railway curves corresponding to 1885 and 1895 and extending the straight line to 1910, while the points on steam-railroad curves were 1880 and 1890.

Those curves which when extended give a result contrary to the "characteristic sign" have been thus marked. The number of these shows the indicative nature of the information and its lack of exactness, together with the importance of cross-references to "characteristic signs" and other curves before arriving at a conclusion based on averages in any particular case. These curves might be called "pro-

TABLE No. 26.—RATIOS OF COMPARATIVE STATISTICS OF STEAM RAILROADS AND STREET RAILWAYS. Mr. Davis.

Item number—Table No. 16.	Items.	RATIO OF COMPARATIVE STATISTICS, TABLE No. 16.							
		All electric railways in New England. Table No. 5.	Electric city railways. Table No. 4.	Electric suburban and interurban railways. Table No. 3.	Electric city, suburban and interurban railways. Tables Nos. 3 plus 4.	Electric city railways. Table No. 4.	Electric suburban and interurban railways. Table No. 3.	Steam railroads of New England. Table No. 16.	Street railways of New England. Table No. 16.
1	Number of roads taken	1	0.19	0.36	0.55	1	1.82	1	1.18
3	Length	1	0.26	0.46	0.72	1	1.75	1	0.32
2	Passengers carried	1	0.21	0.25	0.47	1	1.23	1	3.96
12	" earnings	1	0.21	0.26	0.47	1	1.26	1	0.63
6	Car-miles	1	0.26	0.33	0.60	1	1.23	1	0.53 (a)
5	Passengers carried per mile	1	0.80	0.55	0.64	1	0.68	1	12.73
13	Passengers carried per car-mile	1	0.88	0.86	0.87	1	0.97	1	6.77
26	Passengers carried per capita per annum	1 (d)	0.85 (d)	0.47 (d)	0.80 (d)	1	0.55 (c)	1	3.96 (b)
8	Passenger earnings per mile	1	0.78	0.56	0.64	1	0.72	1	2.03
9	Passenger earnings per car-mile	1	0.84	0.88	0.87	1	1.02	1	1.08 (a)
11	Passenger earnings per passenger	1	0.97	1.02	0.99	1	1.05	1	0.16
32	Passenger earnings per capita per annum	1 (d)	0.84 (d)	0.47 (d)	0.80 (d)	1	0.57 (c)	.....	0.63 (b)
4	Percentage of operating expenses	1	1.03	0.97	1.00	1	0.94	1	0.89
19	Operating expenses per car-mile	1	0.85	0.79	0.84	1	0.93	1	0.87 (a)
17	Permanent investment per mile	1	0.99	0.76	0.85	1	0.78	1	.....
18	Capital investment per mile	1	0.90	0.70	0.77	1	0.76	1	.....

(a) Estimated 5 cars per train on steam railroads.
(b) Population served estimated to be the total in New England.
(c) Population served estimated to be that given in Tables Nos. 28 and 29.
(d) Population served estimated to be the total in New England for Column 1, and that given in Table No. 29 for Column 2; Table No. 28 for Column 3; and Tables Nos. 28 and 29 for Column 4.

jection" rather than "prediction" curves; but, nevertheless, they indicate strongly the future, with its lower percentage of earnings on capital invested, lower cost of operation, greater percentage of operating expenses and larger gross revenue coming from that enormous future growth in passenger traffic at low fares with electric propulsion.

When the population and real wealth become fixed, then such growth will cease, but only then, and will fluctuate with prosperity, but this condition is far distant for the United States.

Comparison of City and Suburban Railways.—Tables Nos. 3 and 4 have been prepared in an attempt to make the discrimination between

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roads "in towns" (urban) and "between towns" (interurban). Some of those in either table may more properly belong in the other, but it is believed that the comparative results shown will be borne out in practice.

Suburban roads have been placed in Table No. 3, where their characteristics conformed to the requirements of the table. Tables Nos. 6 and 7 give summaries of Tables Nos. 3 and 4.

From these tables and from Table No. 16 has been calculated Table No. 26, giving ratios of statistics of steam and electric roads. The first five items (1, 3, 2, 12 and 6) show the relative number, length and capacity of roads, for these may affect the other items in the lower part of the table (5, 13, 26, 8, 9, 11, 32, 4, 19, 17 and 18). From this table we have Table No. 27, showing characteristic signs, when comparison is made according to the notation at the top of each column.

TABLE No. 27.

Item.	All Electric Railways in New England to			Table No. 4 to Table No. 3.	Steam railroads to electric railways, Table No. 16.
	Table No. 4.	Table No. 3.	Table No. 3 + 4.		
5. Passengers carried per mile	—	—	—	—	+
13. " " " car-mile	—	—	—	—	+
26. " " " capita per annum	—	—	—	—	+
8. " earnings " mile	-	—	—	—	+
9. " " " car-mile	—	—	—	+	+
11. " " " passenger	—	+	—	+	—
32. " " " capita per annum	—	—	—	—	—
4. Percentage of operating expenses	+	—	+	—	—
19. Operating expenses per car-mile	—	—	—	—	-
17. Permanent investment per mile	—	—	—	—	:
18. Capital " " "	—	—	—	—	:

The characteristics brought out by these figures are the enormous number of passenger trips per capita per annum, per mile of track and per car-mile, and the greater total number carried by the electric roads when compared with the steam railroads; also the larger earnings per mile of track and per car-mile on the electrics. The receipts per passenger per trip are only 16%, while the receipts per capita per annum are only 63% of the steam railroads. The steam road gets greater receipts per trip, but carries each passenger a longer distance, and has to run a disheartening number of cars or train-miles for the passengers carried. The difference is due to the short trips, high fare per passenger and car-mile, and the "leave-at-your-door"

service of electric roads, while each trip is delivered at an extremely low "total cost" to the passenger. Mr. Davis.

Suburban and interurban railways carry fewer passengers per mile, per car-mile, and per capita per annum than city railways. They earn less per mile of track, more per car-mile and per passenger carried, and less per capita per annum. They operate at a lower percentage of gross receipts and about 7% less per car-mile (Table No. 7), while they cost 25% less. A comparison of such roads with steam railroads is a more accurate one than with city railways, but for obvious reasons it could not be made here.

Effect of Population Served.—Tables Nos. 23, 28 and 29, show the approximate population served by each road in Tables Nos. 3 and 4. In locating any new line, it is essential to know, as nearly as may be, the probable business which it will secure. Upon its amount, the cost of the line completed, and the probable operating expenses, will depend the profit of the undertaking. What other similar roads have done, is the criterion upon which we base all estimates, and the three principal units used are (1) revenue per head of population (number of trips per inhabitant per annum). (2) cost per mile, and (3) operating expenses per car-mile or train-mile. The first is that in which we are now interested.

In determining the gross revenue per head of population, the usual method has been to divide the United States into arbitrary sections, such as the groups of States in Poor's Manual (see Fig. 13), and by dividing the gross receipts by the inhabitants of each division determine the average amount contributed by each individual. Of course, each person does not spend this amount, in fact, some do not contribute anything, while others expend many times the average amount each year. The passenger traffic on any road can be divided into the following general classes:

1. Those who live adjacent to the line and are compelled to ride upon it.
2. Those who are compelled to ride but who can take another line just as conveniently.
3. Those who ride for pleasure.
4. Those who come from a distant place by some other means of conveyance and then ride upon the line for any of the other three reasons.

Those of the first class are by all odds the largest in volume, and as they are the most permanent, increasing or decreasing by known amounts in stated census periods, it would be the best possible basis for our figures of receipts per head of "population served." The difficulty is to get at this "population served." An attempt has been made in these tables, in order to show how receipts would vary according to

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TABLE No. 28.—POPULATION SERVED BY ROADS IN TABLE

NAME OF RAILWAY.	Reference No.	Fig. 16. Order according to population served, smallest being No. 1.	Place.	Population served.	Place.	Population served.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
MAINE.						
Augusta, Hallowell & Gardiner	s 1	19	Augusta	10 527	Hallowell	3 181
Bangor, Orono & Old Town	s 2	32	Bangor	19 103	Veazie	(a)
Biddeford & Saco	s 3	23	Saco	6 075	Biddeford	14 443
Lewiston & Auburn	s 4	41	Lewiston	21 701	Auburn	11 250
Portland & Cape Elizabeth	s 5	44	Portland	36 425	South Portland	(a)
Portsmouth, Kittery & York	s 6	12	Kittery	2 864	York	2 444
Rockland, Thomastown & Camden	s 7	14	Thomaston	3 009	Rockland	8 174
Total and average						
CONNECTICUT.	s					
Danbury & Bethel	s 8	22	Danbury	16 552	Bethel	3 401
Derby	s 9	17	Derby	5 969	Birmingham	2 000[b]
Fair Haven & Westville	s 10	55	New Haven	81 298	Westville	(a)
Hartford, Manchester & Rockville	s 11	9	Manchester	8 222	S. Manchester	1 500[b]
Hartford & West Hartford	s 12	54	Hartford	53 230	W. Hartford	1 930
Meriden Electric	s 13	33	Meriden	21 652	Yalesville	(a)
Norwalk St. Ry	s 14	27	Norwalk	17 747	South Norwalk	4 875
Norwalk Tramway	s 15	47	Norwalk	17 747	East Norwalk	(a)
Norwich	s 16	16	Norwich	16 156	Taftville	(a)
Torrington & Winchester	s 17	2	Torrington	6 048	Winsted	(a)
Bristol & Plainville	s 18	6	Bristol	7 382	Plainville	1 993
Central Railway & Electric (New Britain)	s 19	18	New Britain	16 519	Berlin	2 600
Total and average						
MASSACHUSETTS.						
Arlington & Winchester	s 20	7	Winchester	4 861	Arlington	5 629
Athol & Orange	s 21	8	Athol	6 319	Orange	4 568
Braintree & Weymouth	s 22	13	Weymouth	10 866	Braintree	4 848
Bridgewater, Whitman & Rockland	s 23	24	Bridgewater	4 249	E. Bridgewater	2 911
Brockton, Bridgewater & Taunton	s 24	53	Brockton	27 294	Bridgewater	4 249
Brockton & East Bridgewater	s 25	40	Brockton	27 294	E. Bridgewater	2 911
Dartmouth & Westport	s 26	59	Fall River	74 398	New Bedford	40 733
Dighton, Somerset & Swansea	s 27	1	Dighton	1 889	Somerset	2 106
Fitchburg & Leominster	s 28	39	Fitchburg	22 037	Leominster	7 269
Gloucester, Essex & Beverly	s 29	45	Beverly	10 821	Wenham	(a)
Greenfield & Turners Falls	s 30	10	Greenfield	5 252	Montague	6 296
Haverhill & Amesbury	s 31	50	Haverhill	27 412	Merrimack	2 633
Haverhill, Georgetown & Danvers	s 32	42	Haverhill	27 412	Bradford	3 720

No. 3. ELECTRIC SUBURBAN AND INTERURBAN RAILWAYS. Mr. Davis.

Place.	Population served.	Place.	Population served.	Place.	Population served.	Population served	Passenger trips per capita per annum of population served.
(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Farmingdale	(a)	Gardiner	5 491			19 699	41
Orono	2 790	Old Town	5 312	Great Works	(a)	28 705	42
Old Orchard	(a)					20 518	11
						32 951	35
Cape Elizabeth	5 459					42 384	25
Portsmouth (N. H.)	9 827					15 135	53
Rockport	(a)	Camden	4 621			16 304	59
						175 676	36
						19 953	41
Ansonia	10 342					18 311	38
Montowese	(a)	Hamden	3 882	Fair Haven	(a)	86 680	56
Manchester Center	(a)	Rockville	1 000*			11 222	53
Farmington	3 179	Unionville	(a)	Plainville	1 993	60 832	6
Wallingford	6 584					28 736	50
Winnipauk	(a)					23 122	32
South Norwalk	4 875	Westport	3 715	Stamford	15 700	46 813	16
Yantic	(a)	Thamesville	(a)	Sunnyside	(a)	18 156	69
Burrville	(a)	Highland Lake	(a)			7 548	65
Forrestville	(a)	Lake Compounce	(a)			10 375	52
Plainville Center	(a)	Newington Center	(a)			19 119	74
						326 252 (b)	43 (c)
						10 490	31
						10 887	55
						15 714	63
Whitman	4 441	Rockland	5 213	Abington	4 260	21 074	25
W. Bridgewater	1 917	Raynham	1 340	Taunton	25 448	60 248	22
W. Bridgewater	1 917					32 122	11
Dartmouth	3 122	Westport	2 599			120 852	4
Swansea	1 456					5 451	142
Lunenburg	1 146					30 452	71
Hamilton	(a)	Essex	1 713	Ipswich	4 439	42 624	27
						11 548	61
Amesbury	9 798	Salisbury	1 316	Newburyport	13 947	55 106	25
Groveland	2 191	Georgetown	2 117			35 440	13

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TABLE No. 28 (*Concluded*).—POPULATION SERVED BY ROADS IN

NAME OF RAILWAY.	Reference No.	Fig. 16. Order according to population served, smallest being No. 1.	Place.	Population served.	Place.	Population served.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
MASSACHUSETTS (*Continued*).						
Hingham	s 33	3	Hingham	4 564	E. Weymouth	(a)
Hoosac Valley (North Adams)	s 34	37	North Adams	16 074	Adams	9 213
Interstate Consolidated (R. I.)	s 35	46	Pawtucket (R. I.)	27 633	Seekonk	1 317
Leominster & Clinton	s 36	20	Leominster	7 269	Lancaster	2 201
Lowell, Lawrence & Haverhill	s 37	61	Lowell	77 696	Dracut	1 996
Lowell & Suburban	s 38	56	Lowell	77 696	Billerica	2 380
Lynn & Boston	s 39	62	Boston	448 477	Beverly	10 821
Marlborough	s 40	38	Marlborough	13 805	Hudson	4 670
Millford, Hollister & Framingham	s 41	21	Milford	8 780	Hopedale	1 176
Natick & Cochituate	s 42	28	Natick	9 118	Wayland	2 060
Newburyport & Amesbury	s 43	31	Newburyport	13 947	Amesbury	9 798
Newton	s 44	48	Newton	24 379	Waltham	18 707
Newton & Boston	s 45	51	Newton	24 379	Watertown	7 073
Norfolk Central (Dedham)	s 46	11	Dedham	7 123	Norwood	3 733
Norfolk Suburban (Hyde Park)	s 47	43	Dedham	7 123	Hyde Park	10 193
Northampton	s 48	25	Northampton	14 990	Easthampton	4 395
North Woburn	s 49	36	Woburn	13 499	Winchester	4 861
Providence & Taunton	s 50	60	Providence (R. I.)	132 146	Taunton	25 448
Quincy & Boston	s 51	49	Quincy	16 723	Weymouth	10 866
Reading & Lowell	s 52	4	Reading	4 088	Wilmington	1 213
Rockland & Abington	s 53	29	Abington	4 260	Rockland	5 213
Rockport	s 54	34	Gloucester	24 651	Rockport	4 087
Southbridge & Sturbridge	s 55	5	Southbridge	7 655	Sturbridge	2 074
South Middlesex (Natick)	s 56	30	Natick	9 118	Sherborn	1 381
Taunton & Brockton	s 57	52	Brockton	27 294	Taunton	25 448
Wakefield & Stoneham	s 58	35	Wakefield	6 982	Stoneham	6 155
Warren, Brookfield & Spencer	s 59	26	Warren	4 681	W. Warren	(a)
Worcester & Blackstone Valley	s 60	15	Millbury	4 428	Sutton	3 180
Worcester & Marlborough	s 61	58	Worcester	84 655	Shrewsbury	1 449
Worcester & Suburban	s 62	57	Worcester	84 655	Millbury	4 428
Total and average						
Grand total and average						

s 2. Also—
Stillwater ..... (a)

s 15. Also—
Roton Point... (a)
Rowayton..... (a)
Darien..... 2 276
Noroton ..... (a)
Dorlon's Point. (a)
4 276

s 29. Also—
Gloucester 24 651

s 37. Also—
Haverhill..... 27 412
Groveland..... 2 191
W. Newbury.. 1 769
Newburyport . 13 947
N. Andover.... 3 742
49 061

s 38. Also—
Tewksbury.... 2 515

s 39. Also—
Lynn 55 727
Malden 23 031
Marblehead.... 8 202
Melrose..... 8 519
Peabody..... 10 158
Revere 5 668
Salem 30 801
Saugus 3 673
Stoneham 6 155
Swampscott... 3 198
Wenham ..... (a)
Woburn..... 13 499
Hamilton..... (a)
169 631

TABLE No. 3. ELECTRIC SUBURBAN AND INTERURBAN RAILWAYS.

Place.	Population served.	Place.	Population served.	Place.	Population served.	Population served.	Passenger trips per capita per annum of population served.
(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(a)	N. Weymouth	(a)	Hull	2 000*			7 564	119
9 213	Williamstown	4 221					29 508	52
1 317	Attleborough	7 577	N. Attleborough	6 727	Wrentham	2 566	45 820	56
2 201	Clinton	10 424					19 894	43
1 996	Methuen	4 814	Lawrence	44 654	Andover	6 142	184 363	48
2 389	Chelmsford	2 695	Dracut	1 996	Tyngsborough	(a)	87 782	87
10 821	Chelsea	27 909	Danvers	7 454	Everett	11 068	675 360	43
4 670	Southborough	2 114	Framingham	9 239			29 828	25
1 176	Holliston	2 619	Ashland	2 532	S. Framingham	(a)	19 926	83
2 060	Wellesley	3 600	Framingham	9 239			24 017	45
9 798	Merrimac	2 633	Newbury	1 427			27 805	40
18 707	Watertown	7 073					50 159	36
7 073	Needham	3 035	Boston (1/6)	22 423			56 910	19
3 733	Walpole	2 604					13 460	52
10 193	Boston (1/6)	22 423					39 739	48
4 395	Williamsburg	2 057					21 442	84
4 861	Medford	11 079					29 439	27
25 448							157 594	4
10 866	Milton	4 278	Boston (1/6)	22 423			54 290	49
1 212	Billerica	2 380					7 681	43
5 213	Weymouth	10 866	Whitman	4 441			24 780	61
4 087							28 738	19
2 074							9 729	56
1 381	Framingham	9 239	Ashland	2 532	Hopkinton	4 088	26 358	43
25 448	Easton	4 493	Raynham	1 340			58 575	16
6 155	Reading	4 088	Saugus	3 673	Melrose	8 519	29 417	38
(a)	Brookfield	3 352	W. Brookfield	(a)	N. Brookfield	3 871	21 651	44
3 180	Grafton	5 002	Northbridge	4 603			17 213	16
1 449	Northborough	1 952	Westborough	5 195	Marlborough	13 805	107 056	11
4 428	Leicester	3 120	Spencer	8 747			100 950	32
							1 827 517 (d)	49
							2 352 765	43

55 727		
23 031		
8 202		
8 519		
10 158		
5 668		
30 801		
3 673		
6 155		
3 198		
(a)		
13 499		
(a)		
169 631		

§ 41. Also—

Bellingham	1 334
Medway	2 985
	4 319

§ 59. Also—

Spencer	8 747

* Estimated.

(a) Where populations are omitted, the census made no return; for approximation 500 inhabitants are assumed in each case.

(b) This total is 24 615 less than the column foots up, due to repetition of several cities in the table.

(c) If s 12 were omitted, this average would be 51.

(d) This total is 631 546 less than the column foots up, due to repetition of several cities in the table.

Mr. Davis.

TABLE No. 29.—POPULATION SERVED BY ROADS

NAME OF RAILWAY.	Reference No.	Order according to population served, smallest being No. 1 (Fig. 17)	Place.	Population served.	Place.
MAINE.					
Bangor St. Ry.	C 1	15	Bangor	19 103	Brewer
Bath St. Ry.	C 2	3	Bath	8 723	
Calais St. Ry.	C 3	6	Calais	7 290	St. Stephens (N.B).
Portland R. R.	C 4	25	Portland	36 425	Deering
Total and average	...	.....	.....	.....	.....
CONNECTICUT.					
Bridgeport Traction	C 5	27	Bridgeport	48 866	Southport
Hartford St. Ry.	C 6	33	Hartford	53 230	Withersfield
Middletown St. Ry	C 7	8	Middletown	9 013	Portland
New Haven St. Ry	C 8	31	New Haven	81 298	East Haven
New London St. Ry	C 9	9	New London	13 757	Ocean Beach
Stamford St. Ry.	C 10	10	Stamford	15 700	
Winchester Ave. (N. Haven)	C 11	34	New Haven	81 298	Savin Rock
Waterbury Traction	C 12	22	Waterbury	28 648	Waterville
Total and average	...	.....	.....	.....	.....
MASSACHUSETTS.					
Boston Elevated	C 13	35	Boston	448 477	Cambridge
Braintree	C 14	20	Braintree	4 848	Quincy
Brockton	C 15	26	Brockton	27 294	Whitman
Commonwealth Ave. (Newton)	C 16	17	Newton	24 379	
Framingham Union	C 17	5	Framingham	9 239	
Gardner Electric	C 18	2	Gardner	8 424	
Globe (Fall River)	C 19	30	Fall River	74 398	
Gloucester	C 20	18	Gloucester	24 651	
Holyoke	C 21	29	Holyoke	35 637	Chicopee
Pittsfield Electric	C 22	13	Pittsfield	17 281	Dalton
Plymouth & Kingston	C 23	4	Plymouth	7 314	Kingston
Springfield	C 24	28	Springfield	44 179	W. Springfield
Taunton	C 25	19	Taunton	25 448	
Union (New Bedford)	C 26	24	New Bedford	40 733	Fairhaven
Wellesley & Boston	C 27	16	Newton	24 379	
West Roxbury & Roslindale	C 28	21	Boston ($\frac{1}{10}$)	22 423	Dedham
Worcester Consolidated	C 29	32	Worcester	84 655	
Woronoco	C 30	7	Westfield	9 805	
Total and average	....	.....	.....	.....	.....
" " (C 13 omitted)	....	.....	.....	.....	.....
NEW HAMPSHIRE.					
Union St. Ry	C 31	12	Dover	12 790	Somersworth
Nashua St. Ry.	C 32	14	Nashua	19 311	Hudson
Concord St. Ry.	C 33	11	Concord	17 004	
Manchester St. Ry.	C 34	23	Manchester	44 126	
Laconia St. Ry.	C 35	1	Laconia	6 143	
Total and average					
Grand total and average (C 13 omitted)					

C 5. Also East Bridgeport .... (a)

C 6. Also

East Windsor	2 890
Hockanum	(a)
N. Glastonbury }	3 457
S. Glastonbury }	
Burnside	(a)
Newington	(a)
New Britain	16 519
S. Windsor	1 736
E. Hartford	4 455
	30 557

C 8. Also Centerville ..... (a)

C 11. Also

Milford	3 811
Orange	4 537
	8 348

C 13. Also

Newton	24 379
Somerville	40 152
Arlington	5 629
Brookline	12 103
Watertown	7 073
Medford	11 079
Malden	23 081
	123 446

IN TABLE No. 4. ELECTRIC CITY RAILWAYS. Mr. Davis.

Population served.	Place.	Population served.	Place.	Population served.	Population served.	Passenger trips per capita per annum of population served.
4 193	.....	.....	.....	.....	23 296	65
.....	.....	.....	.....	.....	8 723	51
2 000?	Hilltown (N. B.)	(a)	.....	.....	9 790	49
5 353	Westbrook.....	6 632	.....	.....	48 410	112
.....	.....	.....	.....	.....	90 219	87
(a)	Westport	3 715	Fairfield.....	3 868	57 449	71
2 271	Windsor	2 954	W. Hartford...	1 930	90 942	98
4 687	.....	.....	.....	.....	13 700	29
(a)	Morris Cove.....	(a)	Westville.....	(a)	83 298	37
(a)	.....	.....	.....	.....	14 257	46
.....	.....	.....	.....	.....	15 700	39
(a)	City Point.....	(a)	W. Haven.....	(a)	91 146	48
(a)	Naugatuck.....	6 218	.....	.....	35 366	71
.....	.....	.....	.....	.....	401 858	61
70 028	Chelsea.....	27 909	Everett.....	11 068	680 928	266
16 723	Randolph	3 946	Holbrook.....	2 474	27 991	34
4 441	Stoughton.....	4 852	Holbrook.....	2 474	48 884	139
.....	.....	.....	.....	.....	24 379	59
.....	.....	.....	.....	.....	9 239	68
.....	.....	.....	.....	.....	8 424	40
.....	.....	.....	.....	.....	74 398	89
.....	.....	.....	.....	.....	24 651	55
14 050	Northampton.....	14 990	S. Hadley.....	4 261	68 938	61
2 885	.....	.....	.....	.....	20 166	65
1 659	.....	.....	.....	.....	8 973	77
5 077	Chicopee	14 050	Longmeadow..	2 183	65 489	177
.....	.....	.....	.....	.....	25 448	44
2 919	Dartmouth.....	3 122	.....	.....	46 774	80
.....	.....	.....	.....	.....	24 379	29
7 123	.....	.....	.....	.....	29 546	49
.....	.....	.....	.....	.....	84 655	125
.....	.....	.....	.....	.....	9 805	48
.....	.....	.....	.....	.....	1 215 794 (b)	193
.....	.....	.....	.....	.....	581 668 (c)	93 (d)
6 207	.....	.....	.....	.....	18 997	31
1 022	.....	.....	.....	.....	20 403	46
.....	.....	.....	.....	.....	17 004	57
.....	.....	.....	.....	.....	44 126	74
.....	.....	.....	.....	.....	6 143	37
.....	.....	.....	.....	.....	106 673	56
.....	.....	.....	.....	.....	1 180 418	78

C 15. Also Easton.....		4 493
	Randolph	3 946
	Avon.....	1 384
		9 823

(a) Where populations are omitted, the census made no return; for approximation, 500 inhabitants are assumed in each case.
(b) This total is 67 272 less than the column foots up, due to repetition of several cities in the table.
(c) Population served, omitting C 13.
(d) Rides per capita per annum of population served, omitting C 13.

Mr. Davis. the basis of estimates, and how much care must be taken not to be led astray in any given case. If we assume that the steam roads of the New England States serve the entire population, we get gross receipts per head, equal to $7.32, and they undoubtedly do serve this population, but if we were about to build the Boston and Albany Railroad (assuming it did not exist), could we properly use this figure, multiply by the total population and say that would be the probable receipts; or should we take the population within the limits of division (1) "those who live adjacent to the line and are compelled to ride upon it" and multiply by some higher figure, determined from other similar cases? The latter appeals to one as likely to produce much more accurate results. Table No. 16 gives the various amounts per head per annum for various assumed "populations served," from urban communities having, according to the United States census, populations of 8 000 and upward, to and including towns of 1 000 and upward. These divisions of population are not advanced as the proper ones, for they are not, but to bring out clearly what has been said before.

Turning to Tables Nos. 28 and 29, we see great fluctuations in the rides per capita per annum; this is partly due to many causes, such as population, density, distribution, etc., etc., but also due to inaccuracies in determining "population served." From the tables it is seen that the entire populations of towns are repeated for several roads and are considered as being served by and serving these roads; this is necessary unless we can divide the territory, which would be most difficult. If, however, it were done, and it can be, the results would be most interesting and instructive. By the divisions we have made, it is shown clearly that suburban and interurban roads either do not serve as great a population as the aggregate of those forming their terminals and through which they pass, or else the receipts per capita per annum are less from those they do serve. As a matter of fact both propositions are probably true. Our average of 78 in Table No. 29 would have been increased materially had road *C* 13 (Boston Elevated) been included with its 266 rides per capita per annum, but the result would not have been as accurate for application to other problems.

Effect of Competition.—One often hears of the competition which electric parallels have brought to our steam-railroad systems. This has been exaggerated greatly, for most of the traffic of electric railways did not exist until created by low "total cost" and frequent and quick service, although, in certain isolated cases, the building of electric parallels has temporarily drawn away traffic from steam railroads, only to be recovered as the total volume naturally increased. This fluctuation and recovery in traffic, on parallels which changed motive powers, has been shown clearly in the building of elevated and street railways in New York City. The Third Avenue Elevated so decreased the traffic on

the horse surface road as to cause alarm to the stockholders; the conversion of the horse railway to a cable road decreased the travel on the elevated, which was subsequently more than recovered. Mr. Davis.

Fig. 14 gives a good example of the decrease in traffic on the Manhattan Elevated Railway in New York City, operated by steam locomotives, due to the increase in speed and frequency of service on the Metropolitan Street Railway in its changes from horse traction to cable and electric. The loss on the elevated road from 1893 to 1897 was approximately 40 000 000 passengers—part of which was due to the financial depression throughout the United States, as indicated by the "dip" in all curves on Fig. 15; how much this amounts to it is impossible to determine and most difficult to estimate, but an approximation can be made from the retardation of increase shown in the curve on Fig. 15, giving passenger trips on all electric roads in Massachusetts. Projecting the curve by connecting 1893 with 1897 it would indicate a natural proportional increase in 1894 of 17 000 000 more passengers than actually took place, which represents approximately

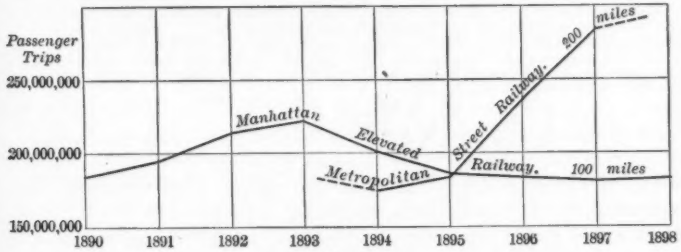

FIG. 14.

the retardation due to the financial depression, or about 7.7% of the total traffic. If we assume the same loss, from the same cause, on the elevated railways, about 17 000 000 of the above 40 000 000 loss is accounted for by the industrial depression, leaving 23 000 000 loss due to competition. During the same period the Metropolitan Street Railway gained about 110 000 000 passengers, or nearly five times as many as the elevated roads lost. The mileage of both roads remained constant, or nearly so, as in the Metropolitan curve are included, for the years taken, all roads now owned or operated by this company. These years also cover the change in motive power of this system. This increase in traffic on the street railways of New York undoubtedly comes largely from increase in speed, better physical conditions, such as track, cars, lighting, heating, cleanliness, open cars, etc., etc.

The elevated railways are operated under the same general conditions as exist on street railways, although the units are heavier, but they are very frequent; of course, they have the disadvantage of being

Mr. Davis.

TABLE No. 30.—EFFECT OF COMPETING ELECTRIC INTERURBAN PARALLELS TO STEAM RAILROADS.

Localities Connected.	Loss due to trolley parallels, as claimed by W. P. Hall of N. Y., N. H. & H. R. R., before Committee, Railroad Committee, Legislature of Connecticut (*a*).	Approximate distance in miles from Railroad Commission Map.	Trips per day as given by time table of N. Y., N. H. & H. R. R.	Trips per day of trolley roads.	Number of passengers carried by Electric Railway System in and between these towns, part of which traveled between them (1894).
Norwalk—Rowayton	50%	4.75	27	84	956 241
Bridgeport—Stratford	$35 per day.	3.00	36	84	4 659 322 (Est.)
Bridgeport—Southport	80%	5.50	23	63	
Waterbury—Naugatuck	90%	6.00	13	69	2 624 421
Wallingford—Meriden	30%	5.50	17	30	2 001 347
Birmingham—Ansonia	90%	3.00	16	112	1 033 977
Winnepauk—S. Norwalk	(*b*) 50%	3.00	....	....	1 090 263
					12 365 571

(*a*) Total loss to N. Y., N. H. & H. R. R. from all parallel trolley roads in the State of Connecticut = $4 000 per month = $48 000 per annum, or ⅛ of 1% loss on total passenger income of $12 971 000 in 1894, as shown by Railroad Commission Reports.

(*b*) 64 passengers were carried on N. Y., N. H. & H. R. R. in the month of December, 1893, and 9 in the same month of 1894, or a total loss of 780 passengers per annum, at a possible maximum of 15 cents = $117.

confined to what might be called "trunk" lines without feeders. These frequent units are now operated by steam locomotives, but a change to electric motors is about to take place. This change is not warranted by any decrease in operating expenses which will take place, either actual or sufficient to offset the interest on the additional investment, although in the first years of electric operation figures will no doubt be produced which will appear to indicate such a result, as in two cases already cited. Nevertheless, the change, if made, will be a profitable one from the natural and induced increase in the traffic of the future, just as the large investments of our steam railroads in improved terminals, track, rolling stock and stations have been justified. Similar results will be the inducements for a change of operative methods on parts of our steam railroad systems, which change necessitates a change in motive power.

Table No. 30 has been prepared from a speech by Mr. Edwin B. Gager before the Railroad Committee of the State Legislature at Hartford, Conn., March 22d, 1895.* For many years bitter warfare has been waged against interurban electric railways by the Consolidated System (New York, New Haven and Hartford Railroad Company) resulting in the electric parallel law, where "public convenience and necessity" must be demonstrated to the satisfaction of the Superior

*Those who are interested can obtain a reprint of Mr. Gager's speech by addressing him at Derby, Conn.

Mr. Davis.

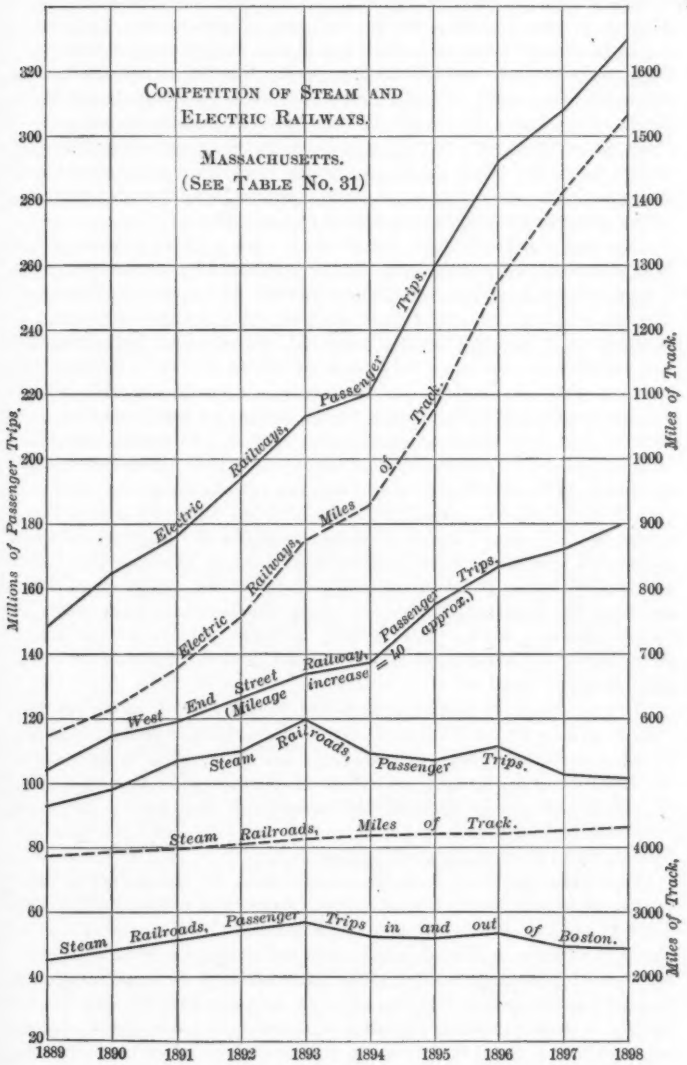

FIG. 15.

Mr. Davis. Court, before an electric railway can be built between two points already connected by a steam railroad. More unwise legislation against a natural progress, which would also benefit those whose influence created it, can scarcely be imagined. It is fair to assume that in this controversy—for the street railways naturally opposed such legislation—both sides produced the strongest arguments in support of their respective contentions; the Consolidated presenting losses of traffic, while the street railways insisted that their passenger travel was mostly an induced one, which did not and could not exist under steam-railroad conditions and operative methods.

An examination of Table No. 30 shows conclusively how the steam railroads convicted themselves. The Consolidated System only claimed a total loss of $4 000 per month, or $48 000 per annum on the entire system, being about ½ of 1% of their gross passenger revenue. If the average fare were 10 cents, this would mean a total loss of 480 000 passengers per annum out of a total of 44 448 324, or 1.1%; but 1894 was the year of financial depression, when the steam railroads of Massachusetts lost 8.3% of their former passenger traffic, so that only part of this loss on the Consolidated was due to trolley parallels. While the total loss to the Consolidated was given by its officers, all the towns between which it occurred were not stated, so that in Table No. 30 the 12 365 571 passenger trips, between and in a few of these towns, is only part of the total passenger traffic of the street railways serving all localities where such loss took place. Whether this figure should be increased by 50 to 100%, or more, we cannot say, but, in any case, the data are sufficient to show the large induced traffic of street railways; or, in other words, systems which give low fares, frequent service, short total time consumed in round trip and a "leave-at-your-door" service.

To emphasize the fact of what might be called a "dormant traffic," which can become an "induced traffic" under proper operative conditions, and to bring out this fact more clearly, Fig. 15 and Table No. 31 have been prepared, and these again show what a small part of the traffic of street railways has come from the losses of steam railroads, and also, that a large part of this loss has been wrongly attributed to electric parallel competition.

The passenger traffic on steam railroads in Massachusetts has increased constantly from year to year since 1870, except during two periods, both of which coincide with industrial depressions; this is shown by Curve 2, Fig. 7, where the loss began in 1873 and 1893. Short-haul passenger traffic is but little affected by financial conditions, when compared with the effect on long-haul traffic; this is due mainly to necessity being the basis of short-haul passenger business, or, in other words, it is composed mostly of commuters or suburban and interurban travel. Curve 2, Fig. 6, corroborates this position,

for we see that the passenger trips on street railways (short hauls, from necessity, as the controlling factors in volume of traffic on these systems), increased after 1874 and 1893, although less rapidly than in the year previous, but there was no actual decrease. This curve brings out another interesting fact, namely, the quicker recovery of electric roads and their more rapid increase in passenger traffic than when operated by horse-power, again supporting our position. In Massachusetts, electric railway mileage has increased along with the passenger traffic (1889 to 1898) 163% in the former to 123% in the latter, or, approximately, each has kept pace with the other. In other words, these railways have been built where traffic did not previously exist, nor could it be produced by the steam railroads under existing conditions; it has been "induced" by the character of the electric roads and their operative methods. Steam railroad mileage has only increased 10% in Massachusetts during the same period, and passenger traffic 9.6% (net). Mr. Davis.

TABLE No. 31.—Comparative Loss on Steam Railroads and Gain on Electric Railways—Massachusetts.—(See Fig. 15).

Year.	Loss in passenger trips per annum on all steam railroads in Massachusetts.	Loss in passenger trips per annum on steam railroads in and out of Boston.	Loss in passenger trips per annum on steam railroads in Massachusetts omitting those in and out of Boston. Column 2 minus Column 3.	Gain in passenger trips per annum on all street railways in Massachusetts.	Amounts in Column 5 divided by those in Column 2.	Gain in passenger trips per annum on West End Street Railway system in and out of Boston.	Amounts in Column 7 divided by those in Column 3.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1889 to 1893....	{ 26 250 648 Increase }	{ 11 406 434 Increase }	{ 14 844 214 Increase }	{ 65 362 606 Increase }	2.4	29 620 468	2.6
1894.....	10 345 763	3 824 940	6 520 823	6 912 090	0.65	3 164 831	0.8
1895.....	1 577 836	740 680	837 156	39 330 209	24.9	18 203 057	24.5
1896 (Increase)	.....	.....	.....	.....	.....	.....	.....
1897.....	8 885 161	3 808 480	5 076 681	16 325 281	1.8	5 692 225	1.4
1898.....	803 168	723 748	79 420	22 205 405	27.6	8 766 782	12.1
1896 (Increase)	21 611 928	9 097 848	12 514 080	.....	.....	.....	.....
	3 772 703	1 483 774	2 288 929	32 564 635	8.6	11 630 782	7.8
Net decrease 1894 to 1898.	17 839 225	7 614 074	10 225 151	117 327 620	6.5	47 457 677	6.2

Turning to Table No. 31 and Fig. 15, we see that the net loss of passenger traffic on all the steam railroads of Massachusetts, from 1893 to 1898, was 17 839 225; but during the same years the street railways increased 117 327 620, or 6.5 times the loss of the steam railroads. If 7.7% of the traffic was lost, due to financial conditions (as estimated heretofore), then only 8 600 000 passenger trips were lost to

Mr. Davis. the steam roads of the State from trolley competition. If the average fare lost was 10 cents (when secured by the street railway the fare would be halved or even less for them), the total amounted to $860 000; or 2.4% on the gross passenger earnings and 1.1% on the gross earnings of the steam railroads; this would only amount to about 1% of the total net earnings. Again, the net loss to steam railroads in and out of Boston, from 1893 to 1898, was 7 614 074, while the West End Street Railway (controlling practically all street railways in and out of Boston), increased 47 457 677 or 6.2 times the loss of the steam roads. Applying the same argument, only 3 225 000 passengers were lost by the steam roads in and out of Boston, due to this competition. This would not be fair, however, for this traffic is made up more largely of commuters than long-haul passengers. Assume it at 5 000 000, which is undoubtedly too high, and with an average commutation rate of 7 cents, the loss is only $350 000 at the maximum. Furthermore, the greatest gains of the street railways throughout the State, and the West End Street Railway alone, were in 1895 and 1898, when the steam roads lost the least. All these data point to the conclusion, already stated, that competition does not take place to the extent usually believed; while an "induced" traffic is created by the low fares, frequent, quick and "leave-at-your-door" service, rendered possible by the physical characteristics and operative methods of the electric roads.

Fig. 16 is from Table No. 28. Populations are arranged in the order of magnitude as abscissas, beginning with the smallest served, while the passengers per capita per annum are ordinates. The resulting curve shows no well-defined law.

Fig. 17 is the same from Table No. 29, and indicates plainly that as populations increase, the rides per capita per annum also increase.

Fig. 18 is made from towns arranged in the order of their density of population. The curve shows no well-defined law.

The determination of the desirability or undesirability of substituting electric traction for steam on parts of some American railroad systems is a matter of constantly increasing importance; on many projected lines the question whether steam or electricity shall be used is a problem which must now be solved, although in the past there was no question as to which should be adopted. We will probably see during the next ten years a large increase in the substitution of electricity for steam on railroads. This change is foreshadowed by the present electrical equipment of elevated railways in Chicago; by the overhead-trolley and third-rail experiments of the New York, New Haven & Hartford Railroad Company; by the operation of several branch lines of the Pennsylvania Railroad Company with electric motors; and by the present active discussions, among steam-railroad engineers and managers, of the details of first cost, operating expenses, and methods of electric traction.

Mr. Davis.

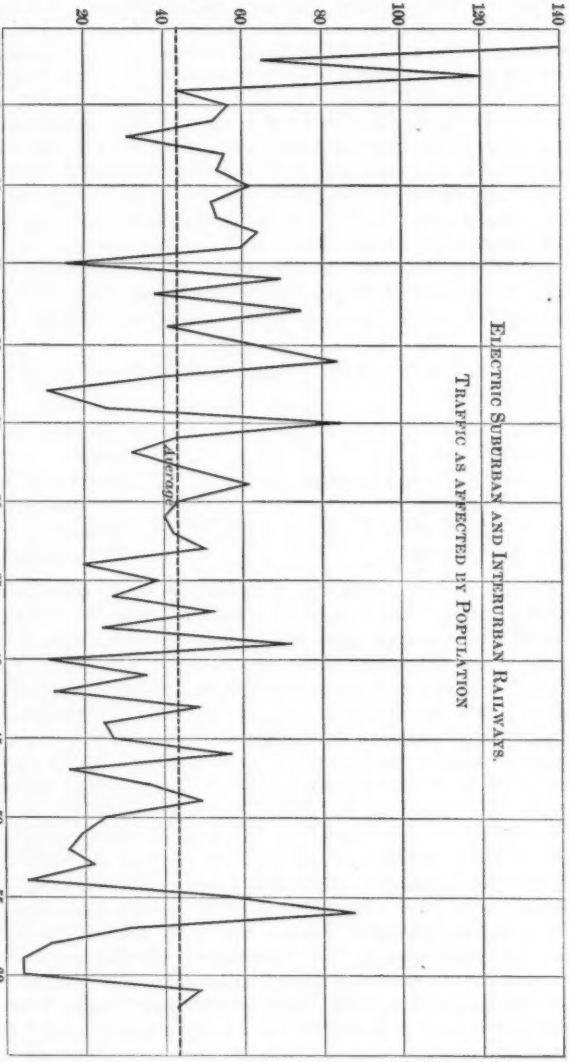

FIG. 16.

Mr. Davis. If a change is contemplated, steam-railroad managers must avoid making the mistake which took place in the change from horse traction to electric traction—namely, of trying to reduce the first cost of changing by the use of old methods, material, and equipment, which, although entirely suited to the old system, proved most unsatisfactory under the new conditions. The old equipment partly made over will not do. There must be new trucks, and new and lighter car bodies, hung lower for greater ease of entrance and departure. Old methods of operation must be discarded and new ones substituted. A change of system may necessitate additional tracks, which should be provided even at large cost. The nearer the approach to the "leave-at-your-door" service, the greater the success.

Let us consider some examples where it is probable that electricity could be substituted with profit, remembering that more thorough investigation might show, in this or that case, that the change is undesirable.

Suburban service of the Pennsylvania Railroad, out of Philadelphia, as follows:

P., W. & B.	Division to	Wilmington.
Main Line	"	" Paoli.
Germantown & Chestnut Hill	"	" Chestnut Hill.
Reading	"	" Norristown.
U. R. Rs. of N. J.	"	" Tacony.
West Chester	"	" West Chester.

By the use of multiphase currents and rotary-transformer sub-stations, power houses could be located along the Delaware and Schuylkill rivers; from these sub-stations direct current at 500 volts could be fed into the trolley or third-rail line. The equipment should be entirely new; cars of the same seating capacity, but lower and of lighter construction, should be used; the bridge over the Schuylkill River into Broad Street Station should be widened by four additional tracks; main line and U. R. Rs. of N. J., by two tracks, each; P. W. & B. should have a total of four tracks; Germantown & Chestnut Hill, Reading, and West Chester should each have a total of three tracks; all tracks should be equipped electrically, although some of them would be used by steam locomotives hauling freight and through passenger trains, and some or all, at times, by both systems. Two tracks should be laid in the street from Broad Street Station to the Schuylkill Bridge coming to railroad grade at that point; the cars running over these tracks should operate from the Delaware River out Market Street, by trackage arrangement with the street railway or by special franchise, the street being wide enough for four tracks; they should be run as any street-railway line is run to-day, and continue out on the extra tracks, provided above, as far

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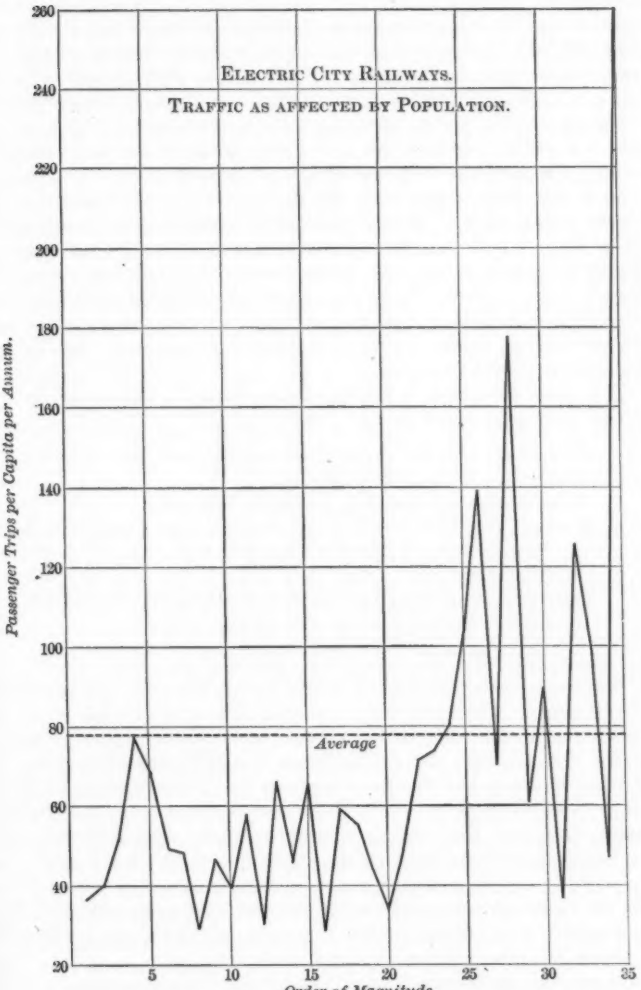

FIG. 17.

Mr. Davis. as circumstances might warrant, and should be extended as travel required; right-of-way should be prepared, so that passengers could leave or enter these cars at any point along the line. Local stations should be provided, in some cases much closer than at present, at which passengers, on the cars mentioned above, could change to electric cars stopping only at said stations, or to express electric trains stopping at fewer points, all being done by the payment of a single fare. It will be seen that this is a combination of the street railway on the outside tracks with the local and express service of a steam road on the inside tracks, while the through locomotive trains operate on the middle tracks. The proposition is a radical one, is advanced as such, and will bear close investigation and study; the expense would be enormous, but the gross receipts from such a system of street railways, accumulating passengers for the rapid-transit system connected so intimately with it, would also be enormous—in fact, the writer believes, far in excess of anything yet accomplished in the transportation of passengers.

The same treatment of the following terminals, with modifications to suit each case, would be worth studying:

New York, New Haven and Hartford Railroad, out of Boston.
Boston and Maine, out of Boston.
Philadelphia and Reading, out of Philadelphia.
Harlem, New York Central and Hudson River, and New York, New Haven and Hartford Railroad Companies, out of New York City.
Central Railroad Company of New Jersey, out of Jersey City.
Illinois Central Railroad, out of Chicago, etc., etc.

The above is, of course, only a suggestion of details.

As an example of interurban traffic, we can take Ansonia and New Haven, Conn. When the steam railroad owns the systems of street railways in both towns, their cars will pick up passengers at either center, will pass onto the present steam tracks on the right-of-way of the New Haven and Derby Railroad (New York, New Haven and Hartford Railroad Company), run at high speed without stops to the other center, pass onto the local street railway tracks there and distribute its passengers where they desire, all for one fare. Such a system operated by electric motors would be a financial success, where a line like the third-rail between Hartford and New Britain is a failure in the true sense. Many other similar examples might be given, but this indicates the future of our steam railroads.

It must not be inferred that all or any of the cases suggested above, if thoroughly investigated, would prove the expense warranted, especially that of laying additional tracks. It is, however, the writer's judgment that in most cases additional tracks would be necessary to

make the system profitable and able to handle the "induced" traffic. Emphasis must be placed upon the importance of radical changes in present steam-railroad methods to make the change to electricity pay. Electric traction in connection with existing tracks and equipment, and under existing operative methods, will result in heavy loss and ultimate abandonment of the change—possibly even in disaster. Mr. Davis.

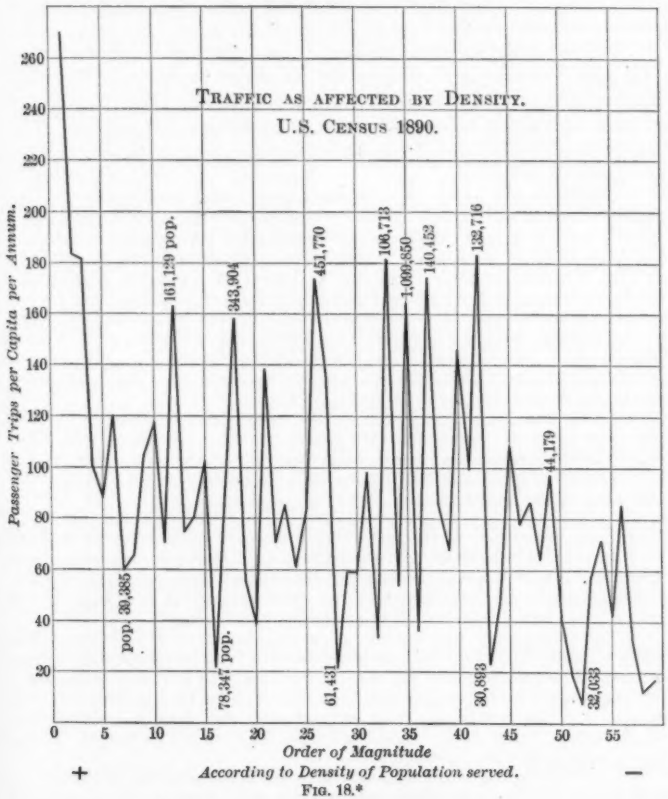

Fig. 18.*

The argument has thus far been confined, for reasons stated, to suburban and interurban short hauls, and the writer feels convinced from his investigation of the subject that the adoption of electricity as a mode of operation, with the additional change to the prevailing

* The data for the diagram, Fig. 18, are taken from Table No. 39 of "Facts and Figures Interesting to Electric Railway Men" (3d edition), published by the writer.

Mr. Davis. methods of our present street railways giving nearly the same class of service (combined or not with steam locomotives as the case may require), will result to the steam roads in an enormous increase of the total passengers carried, passengers per car-mile and rate received per mile, and will shorten the length each passenger is hauled; and, by thus increasing the gross receipts, will more than pay for the additional investment. If this cannot be done in any given case, then it will not pay to make the change.

In conclusion, the writer wishes to quote from the final paragraphs of a paper presented by him to the American Institute of Electrical Engineers,* wherein was expressed the convictions given in this discussion, and which he sees no reason to change at this writing. This was prior to the third-rail experiments of the New York, New Haven and Hartford Railroad.

"The question whether the gross receipts of a given road will be affected by the use of one or the other power under discussion is a most interesting one. Experience shows that where an electric road has paralleled a steam road it has taken most of the latter's business at first, but less as time went on; and that it created a demand for intercommunication which had never existed before—the bulk of the passenger travel coming from this cause. This is interestingly shown in the arguments of Judge Hall (Vice-President of the New York, New Haven and Hartford Railroad) and Judge Gager, of Connecticut, before the Legislature of the State at its last session. This, of course, refers to passenger receipts only. Freight receipts would not be affected by the use of one power or the other, they increasing only as the country grows and rates fall, together with better facilities. Receipts from express and mails might be materially increased by the use of electric traction when giving more frequent service. It appears that the close headway and 'leave-at-your-door' service of electric roads are the main reasons for their induced travel. The question of how much more the travel would be increased by the use of electric traction and frequent service is problematical, for the 'leave-at-your-door' service is wanting in steam railroads as they are, but why not change them? If this could be done, past experience and data would give a good basis from which to estimate future results.

"The conclusion one arrives at is that for long lines, infrequent service, where freight is a large proportion of the business, and where centers of population are far apart, the steam locomotive is the only paying method of to-day, as the first cost will be less, as well as total expenses. The writer has had several opportunities of determining these facts. What development may bring to electric traction in the far future cannot be foretold.

"The writer believes that electric traction will be profitable to steam railroad systems when some or all of the following conditions are fulfilled, depending upon the special problem to be solved:

"1. Steam railroad managers must avoid making the mistake which took place in the change from horse traction to electric traction, namely, of trying to reduce the first cost of changing by use of old methods, material and equipments, which, although entirely suited to

* Meeting of October 21st, 1896.

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the old system, proved most unsuitable under the new conditions. The tendency is to repeat this mistake, and too much stress cannot be laid upon avoiding it. The old equipment partly made over, the old method of operating, etc., will not bring success in the use of electric traction; and if followed from necessity would indicate the strongest argument against the change.

"2. Long distance, heavy trains and infrequent service, if a necessity, will prevent electric traction being profitable. Therefore, where gross receipts can be increased by light trains and frequent service, and thus decrease expenses, as compared to steam locomotives, electric traction will prove profitable. One of the best examples of how this could be applied is found in the suburban service of the Pennsylvania Railroad out of Philadelphia. It is, of course, understood that electric cars can be operated over the same tracks as trains drawn by steam locomotives; a change of system requiring more frequent service for success might necessitate one or more additional tracks, which in some cases would delay the time when a change would be advisable.

"3. Steam railroads, where the second condition is fulfilled, can better the results where they operate part of the system on the 'leave-at-your-door' plan. This suggestion may seem to some a radical departure, but I commend it to the careful thought of those interested."

The writer's final conclusion is that electric traction can be profitably used:

(1) Where units are so light and so frequent, and carried such short distances, that steam locomotives cannot be furnished at lower first cost or operated more cheaply, as in the plain case of a street railway.

(2) Where the gross receipts will be so increased by the change of system and the mode of operation as to more than pay for the increased first cost and operating expenses per car-mile, as in the case of suburban steam systems running out of our great cities and interurban systems between large towns situated a few miles apart.

(3) When competition of parallel electric roads compels the change to save what traffic there is, irrespective of the question whether it will be more profitable.

(4) Where higher speeds are required than can be attained by steam locomotives.

High Speed Railroads.

This discussion would not be complete without reference to another field where electric motors will prove a profitable method of operation, namely, (4) where higher speeds are required than can be attained by steam locomotives. This discussion is already long enough, so that the consideration of this must be postponed, but the reader is referred to "Enormous Possibilities of Rapid Electric Travel," by the writer.*

* *Engineering Magazine*, 1897.

Mr. Davis. In that paper is expressed the belief that large centers of population, reasonably near together, will eventually be connected by railways operating at 150 miles per hour or over, with the local street railways as feeders and distributors.

Many more interesting facts and deductions can be obtained from a careful examination and analysis of the curves and tables. They are left to the intelligence of the reader.